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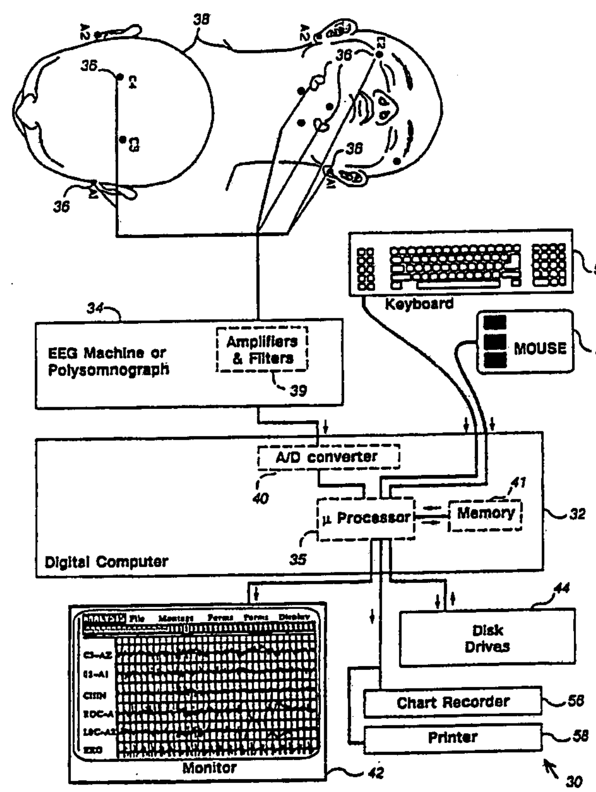
(54) Title: COMPUTER ASSISTED ANALYSIS OF SLEEP

(57) Abstract

A computerized apparatus for assisting an operator in analyzing physiological signals occurring during sleep and in scoring the stages of sleep. To teach the computer system how to analyze the physiological signals and for scoring the stages of sleep, the operator establishes initial values of parameters that distinguish events in the recorded data. Events in a portion of the recorded data are then identified using the initial parameters and the results of this identification are displayed for the operator's review. The operator then classifies the events into those that have been identified correctly and those that have been identified incorrectly. Using this event classification, the computer then adjusts the parameters to conform with the correctly identified events. Alternatively, the operator enters selected physical characteristics about a subject, e.g. the subject's age, sex, etc. These physical characteristics are then used to retrieve an initial protocol from a library of previously recorded protocols. Data recorded for the physiological signals is then scored using this initial protocol after which a second protocol is then retrieved from the protocol library based upon the results of scoring with the initial protocol. Various display formats provided by the computer program allow an operator to review the computer assisted sleep analysis in numerous different ways and to associate textual comments with epochs in the data.



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COMPUTER ASSISTED ANALYSIS OF SLEEP

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to computer assisted analysis of physiological data and, more particularly, to computer assisted analysis of sleep.

Description of the Prior Art

The existence of disorders in sleeping and in waking-up has been recognized for centuries. Accordingly, various disorders are now well recognized and a classification system for such disorders was adopted in 1979. This classification system recognizes distinct disorders in initiating and maintaining sleep (insomnias), in excessive somnolence, in the sleep-wake schedule, and dysfunctions associated with sleep, sleep stages, or partial arousals (parasomnias). Included among the preceding major categories of disorders and dysfunctions are various syndromes such as sleepwalking, nightmares, sleep related asthma, sleep apnea, alveolar hypoventilation, narcolepsy, and epilepsy related to stages of sleep.

To identify and classify these and other sleep related disturbances, both researchers and clinicians now employ a standardized terminology, techniques and scoring system for the various stages of sleep in humans. This standardized terminology,

techniques and scoring system, which was published in a 1968 manual authored by A. Rechtschaffen and A. Kales, is based upon observing and/or recording specific physiological signals. In particular, at least four different physiological signals, consisting of two electro-encephalographic ("EEG") signals, one electro-myographic ("EMG") signal and one electro-oculographic ("EOG") signal, are usually recorded throughout an entire night's sleep. In addition to these four essential signals, additional signals such as an electro-cardiac ("EKG") signal, a respiration signal, a blood oxygen saturation signal ("SaO2"), and/or other signals may also be recorded throughout the night. Subsequently, this data is summarized for successive short intervals of time during the night, typically 30 seconds in length although intervals having different durations such as 20 seconds or 60 seconds may be used. During each of these successive intervals, which are called "epochs," the recorded physiological data is analyzed to assign each epoch to one of the seven different categories of sleep established in the Rechtschaffen and Kales scoring system.

Despite the existence of a standardized scoring system for summarizing epochs during a night's sleep, in practice analysis of actual data remains somewhat subjective. For example, analysis of a night's data is influenced by a patient's age. Similarly, the absence of other activity such as alpha rhythms, rapid eye movements, sleep spindles, etc. in the physiological data

influences the scoring of sleep. The ability to properly adapt analysis of sleep data to an absence of alpha activity is particularly important since approximately 10% of the population does not exhibit alpha activity. Thus, in practice, the Rechtschaffen and Kales scoring system is applied flexibly depending upon the characteristics of individual subjects.

Traditionally, the physiological data for an entire night has been recorded using a multi-channel ink-on-paper strip chart recorder. This record is then manually analyzed to score the various stages of sleep. Because certain signals such as the EEG have significant components with frequencies as high as 90 Hz, the recording paper generally passes through the chart recorder at a linear velocity of 10 to 20 mm/sec. Consequently, using this multichannel recording technique, the data for a single night's sleep is extremely bulky and occupies several thousand pages of recording paper. Obviously, the manual summarization of the data recorded on this volume of paper is time consuming, clumsy and awkward, particularly if it is desirable to juxtapose and compare the data for two different epochs of sleep that are widely separated in time.

Furthermore, the traditional recording technique for analyzing sleep data is poorly adapted to recording and analyzing snoring. The audible signals that occur during snoring contain significant information in frequencies extending up to several kilohertz.

However, such audible frequencies are 500 to 1,000 times higher than the maximum frequency of the EEG signals recorded during sleep. Obviously, if audible signals associated with snoring were recorded directly onto a strip chart, the number of pages recorded during a night would increase by 500 to 1,000 times over that presently being recorded. Similarly, if only the envelope of the audible signals associated with snoring were recorded directly on to a strip chart, the number of pages recorded during a night would increase by 50 to 100 times over that presently being recorded.

Alternatives to manual analysis for scoring sleep have been disclosed. For example, a 1972 paper entitled "Pattern Recognition of EEG-EOG as a Technique for All-Night Sleep Stage Scoring" by Martin et al., which was published at pages 417-427 of Electroencephalography and Clinical Neurophysiology, discloses digital computer scoring of the stages of sleep. As described in this paper, Fourier analysis is applied to successive 30 second epochs of the EEG signal and the results combined to obtain a set of frequency spectral data at 1 c/sec. intervals. Pattern recognition is then applied to this frequency spectral data to score the stages of sleep.

Contrasting with the spectral analysis technique described above, a paper entitled "A Practical Method for Automatic Real-Time EEG Sleep State Analysis" by Lim and Winters, which was published at pages 212-220 in the April 1980 issue of the IEEE Transactions

<u>on Biomedical Engineering,</u> Vol. BME-27, No. 4, discloses a computer, time domain analysis of the waveform of the recorded signals to score the stages of sleep. The time domain technique described in this paper uses peak detection to identify faster waves and zero crossings to detect slower waves. The high frequency wave is characterized by the time difference between successive positive peaks and by the amplitude difference between the positive peak average and the intervening negative peak. If the equivalent frequency of a high frequency wave lies outside the range of 6 to 32 Hz it is rejected. The low frequency wave is characterized by the time difference between successive zero crossings and by the amplitude difference between consecutive peaks. If the equivalent frequency of a low frequency wave lies outside the range of 0.5 to 6 Hz, it is rejected. Various parameters controlling this analysis may be changed from a computer console and the results of the waveform analysis are displayed graphically.

A paper entitled "Pattern Recognition in Sleep Research" by Othmer et al., which was published at pages 596 - 603 in the <u>Proceedings of the Fifth International Conference on Pattern Recognition</u> held Dec. 1-4, 1980, discloses an empirical, digital computer method of time domain feature extraction from raw EEG data based upon bisector turning point analysis. Various terms from the output of this bisector turning point analysis are then combined

to form a ten dimensional feature vector which discriminates among various EEG patterns.

The published Patent Cooperation Treaty ("PCT") patent application no. PCT/US88/02096 entitled "Method and System for Analysis of Long Term Physiological Polygraphic Recordings," filed by Nicolet Instrument Corporation in the name of Martens et al., also discloses a system for computerized sleep scoring and display. The technique for scoring signals disclosed in this patent involves a three step procedure of feature extraction, pattern detection, and then classification.

As disclosed in this patent application, feature extraction depends upon the particular signal being analyzed and employs various parameters such as amplitude, frequency, time of occurrence and duration. Features are extracted in real time for each successive 30 second epoch throughout the night. Concurrently with feature extraction, samples of the unprocessed data are also stored in long term computer storage at a resolution selected to allow reclassification of the data if that is required. The frequency analysis portion of feature extraction is performed using adaptive Fourier analysis for the EOG and EMG signals, and for five mutually exclusive frequency bands in the EEG signal.

Pattern detection for the EEG, EOG and EMG signals consists in identifying "transient pattern candidates" in each of those signals that satisfy four different categories of detection

criteria. The first category of detection criteria employs the extracted features to identify transient pattern candidates in individual signals. The second category of detection criteria involve the synchronism or lack thereof between a particular transient pattern candidate in one signal and concurrent events in other signals. The third category of detection criteria involve the context in which a particular transient pattern candidate occurs in terms of its relationship with other types of patterns or measured variables. The fourth category of detection criteria identify patterns as a combination of other, previously identified patterns.

The computer system disclosed in this PCT patent application scores successive 30 second epochs of sleep into six classes -- awake, rapid eye movement ("REM") sleep, and sleep stages I - IV. Classification is performed by checking whether the EEG, EOG and EMG patterns in each epoch fulfill the criteria that identify one of the 6 classes of sleep. If the criteria for all of the six classes are unsatisfied, the epoch is designated as undefined.

The parameters used in performing each of the three preceding steps may be taken from a "Knowledge Base," and may be interactively changed by the operator prior to initial processing and/or reclassification. In interactively changing the processing parameters, an operator may graphically change threshold levels and/or disable or activate classification rules. The systems

graphically displays sleep scoring results for an entire night, and permits interactive enlargement of the signals for selected short intervals at any time throughout the night. Also various stages of sleep may be selected interactively for which mean values of the stages are then calculated from the recorded data. An operator may then use these results in interactively changing the processing parameters before rescoring the data.

Another example of computerized sleep analysis is disclosed in United States Patent No. 4,776,345. During sleep, the method and apparatus disclosed in that patent performs Fast Fourier Transform ("FFT") processing on the EEG signals to extract frequency information while simultaneously extracting signal strength information from the EMG signal. As disclosed in the patent, thresholds are then assigned to these extracted signals interactively at a display and input module with reference to a graphic representation of the extracted data. The interactively assigned thresholds are applied to the extracted EEG and EMG data and, together with EOG data obtained during sleep, are used in scoring successive epochs to different stages of sleep. This patent discloses that the stages of sleep are scored using the extracted data and a set of assignment rules adapted from the Rechtschaffen and Kales sleep scoring system. The results of this computer scoring of the stages of sleep are then presented

graphically on the display and input module in the form of a hypnogram.

SUMMARY OF THE INVENTION

The present invention provides an improved apparatus for recording physiological data throughout a night's sleep and for analyzing that data after it has been recorded.

An object of the present invention is to provide an apparatus that facilitates quickly analyzing physiological data recorded throughout a night's sleep.

Another object of the present invention is to provide an apparatus that increases the accuracy of sleep scoring.

Another object of the present invention is to provide an apparatus that permits easily and conveniently changing among various different displays of the results of sleep analysis.

Another object of the present invention is to provide an apparatus that simultaneously displays different types of physiological data recorded throughout a night's sleep at differing time scales.

Another object of the present invention is to provide an apparatus that can be interactively taught protocols for sleep scoring.

Another object of the present invention is to provide an apparatus that facilitates applying different protocols for re-scoring physiological data recorded throughout a night's sleep.

Another object of the present invention is to provide an apparatus that provides a library for storing protocols for sleep scoring.

Another object of the present invention is to provide an apparatus that may record and analyze audible events that occur during sleep.

Yet another object of the present invention is to provide an apparatus for the scoring of sleep which is both simple and cost effective, and which facilitates the scoring of sleep.

Briefly, the apparatus of the present invention includes a computer system specially adapted to assist an operator in analyzing sleep and in scoring the stages of sleep that occur throughout an entire night. To perform this scoring using the apparatus, the operator first identifies the several physiological signals for which data is recorded. After the physiological signals have been identified, the operator then selects among various different formats for graphically displaying the recorded data. Having selected a display format, the operator then establishes a set of parameters that identifies a specific waveform in the physiological signals that characterize a particular type event in the recorded data. The computer then scores events

occurring throughout the night's sleep by applying these parameters, i.e. a data analysis protocol, to the recorded data. The computer then provides a graphic display of the scoring results for the operator's review and possible re-scoring using a different protocol.

In one aspect of the invention, the operator establishes the protocol, by first selecting a set of initial values for distinguishing events in the recorded data. This initial protocol is then used to identify events in a portion of the recorded data and the results of this trial event identification are displayed for the operator's review. In reviewing this trial identification, the operator classifies the events into those that have been identified correctly and those that have been identified incorrectly. Using this event classification, the computer then adjusts the parameters to conform with the correctly identified events. These adjusted parameters are then applied to the recorded data in scoring the night's sleep. Thus, an operator may interactively "teach" the computer the particular way in which a subject's sleep is to be scored.

In another aspect of the invention, the operator enters selected physical characteristics about a subject, e.g. the subject's age, sex, etc. These physical characteristics are then used to retrieve an initial protocol from a library of previously recorded protocols. Data recorded for the physiological signals

is then scored using this initial protocol after which a second protocol, to be used in scoring the night's sleep, is then retrieved from the protocol library based upon the results of scoring with the initial protocol.

The various display formats provided by the computer program allow an operator to review the computer program's sleep analysis in numerous different ways. These various display formats allow displaying a summary of the scoring of successive 30 second epochs of sleep into eight different classes -- movement time, waking state, REM sleep, sleep stages I - IV or arousal. The formats also allow displaying hypopnea and apnea events and whether such events were central, obstructive, or mixed.

These and other features, objects and advantages will be understood or apparent to those of ordinary skill in the art from the following detailed description of the preferred embodiment as illustrated in the various drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram depicting a digital computer system for use in the collecting and analyzing sleep data when executing a sleep analysis computer program;

FIG. 2 is a block diagram depicting the hierarchy of menus provided for controlling the operation of the sleep analysis computer program;

FIG. 3 illustrates graphical display of a single thirty second epoch of several different physiological signals in a polygraph display format;

FIG. 4 illustrates graphical display of several different physiological signals in a staging display format which enlarges a single epoch of different physiological signals, such as might be displayed in FIG. 3, into three contiguous 10 second intervals;

FIG. 5 illustrates graphical display of several different physiological signals in a respiratory display format which displays four physiological signals particularly relevant to analyzing respiratory disturbances;

FIG. 6 illustrates a respiratory disturbance log superimposed over the respiratory display format depicted in FIG. 5;

FIG. 7 illustrates a graphical display of the same physiological signals during different epochs in the recorded data;

FIG. 8 illustrates the parameters used in automatic scoring of sleep staging;

FIG. 9 illustrates the hypnogram display format for displaying the results of sleep scoring;

FIG. 10 illustrates the summary display format for displaying the results of sleep scoring and respiratory analysis;

FIG. 11 illustrates a graphical display of different physiological signals with differing time intervals over which the various signals are displayed; and

FIG. 12 illustrates a graphical display of two different physiological signals, each being displayed with different durations of data.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 depicts a digital computer system in accordance with the present invention, identified by the general reference character 30. The digital computer system 30, which includes a microcomputer based digital computer 32, is connected to either an EEG machine or polysomnograph 34 to adapt it for collecting and analyzing sleep data. The digital computer 32 is preferably an IBM/AT compatible microcomputer that includes either an 80386 or 80268 microprocessor 35 that respectively runs at a clock speed of 20 MHz or 16 MHz.

Several electrodes and other sensors 36 are connected, in a conventional manner, from the EEG machine or polysomnograph 34 to obtain physiological signals from a subject 38 whose sleep is to be scored. As depicted in FIG. 1, a pair of EEG electrodes 36 are attached to the subject 38 to provide a A1-C4 EEG signal to the EEG machine or polysomnograph 34, while other electrodes and sensors 36 are connected to the subject 38 to provide an EOG and an EMG signal. During data collection, the EEG machine or polysomnograph 34 passes analog signals from the electrodes and other sensors 36 through amplifiers and filters 39 and then transmits the amplified

and filtered signals to the digital computer 32. Included within the digital computer 32 is an analog-to-digital ("A/D") converter 40 that receives, from the EEG machine or polysomnograph 34, the analog signals representing the signals present at the electrodes 36 attached to the subject 38. The A/D converter 40 included in the digital computer 32 may be selected from various different types offered by several manufacturers such as the Burr-Brown model PCI-20098CI 12 bit A/D together with a Burr-Brown model PCI-20002M-1 analog expander.

The A/D converter 40 included in the digital computer 32 converts the analog EEG, EOG and EMG signals into binary numbers every 5 to 10 milliseconds, and then stores the digitized value into a memory 41 of the digital computer 32. While these analog signals are preferably converted into digital values every 5 to 10 milliseconds, because the EEG and EOG signals have significant information up to 200 Hz, it may be beneficial to convert a sample of these signals into digital form as frequently as every 2.5 milliseconds. Alternatively, the EMG signal may have significant information up to 600 Hz which might require converting its signal every 0.8 milliseconds. Since the A/D converter 40 of the preferred embodiment is capable of simultaneously receiving and digitizing up to 32 different signals, other signals frequently used in the scoring of sleep such as EKG and respiratory measures such as airflow, thoracic and abdominal effort, and blood oxygen

saturation, SaO2, may also be concurrently digitized and stored into the memory 41 of the digital computer 32.

As the signals are being digitized by the A/D converter 40 under the control of a sleep analysis computer program executed by the digital computer 32, they may be displayed on a high resolution color video monitor 42 connected to the digital computer 32. Also, as the signals are being digitized they are stored onto computer disk drives 44. While the computer disk drives 44 preferably include a Write Once-Read Many ("WORM") large capacity optical disk, other types of disk memories such as floppy-disks, removable cartridge disks and/or fixed, internal hard-disks may also be included in the computer system 30. The digital computer system 30 also includes a keyboard 52 and a mouse 54 that an operator uses in interacting with and controlling the operation of the digital computer 32 for recording and analyzing sleep. In addition to the video monitor 42 for displaying the recorded data and the results of its analysis, the digital computer system 30 may also include a printer 56 and/or a chart recorder 58 for producing permanent, human readable copies of displays appearing on the video monitor 42.

Sleep Analysis Computer Program

The sleep analysis computer program executed by the digital computer 32 that controls the overall operation of the computer system 30 is invoked by a command to an operating system, MS-DOS, running on the digital computer 32. This sleep analysis computer program is organized as a series of menus presented to the operator on the video monitor 42. To control the operation of the computer system 30, the operator selects an item from the menu presently displayed on the video monitor 42. There are three different ways that an operator may make such a selection. The first way is using the mouse 54 to move a cursor across the screen while holding the left hand button down on the mouse 54 until the desired option is highlighted on the video monitor 42. When the desired option is highlighted, the operator selects that option by releasing the left hand button on the mouse 54. Alternatively, the "TAB" key or the "ARROW" keys on the keyboard 52 may be used to highlight the desired option which is then selected by pressing the "RETURN" key on the keyboard 52. Finally, each menu option name includes an uppercase, or capitalized, letter. The option may be selected directly by pressing the corresponding key on the keyboard 52. The sleep analysis computer program responds to each successive menu selection by performing the selected action which may be either the execution of a program function, providing the display of another

menu from which additional selections may be made, or providing access to a set of commands.

FIG. 2 depicts the hierarchy of menus provided by the sleep analysis computer program illustrating how menus are invoked from other menus. At the top of the hierarchy is a main menu 62 which provides the only access into and out of the program. Just below the main menu 62 are a data collection menu 64 and a data analysis menu 66, which are the primary menus for controlling the program's operation. Also available from the main menu 64 is a temporary exit menu 68 that allows temporarily suspending execution of the sleep analysis computer program and returning control of the digital computer 32 back to the operating system MS-DOS. Execution of the sleep analysis computer program may be resumed precisely at the point of exit if it has been exited to MS-DOS through the temporary exit menu 68. Conversely, execution of the sleep analysis program may not be so resumed if an exit menu 72 is selected from the main menu 62.

Data Collection

Selecting collection in the main menu 62 puts the sleep analysis computer program in the data collection mode and causes the collection menu 64 to be displayed. There are two ways an operator may specify a data collection protocol for the computer program. The first is to set up a data collection protocol by

interactively reviewing each program option affecting the collection and display of sleep data, adjusting parameter values if necessary. The second way of preparing the computer program for data collection, which is very convenient, is to re-use a previously stored system protocol. Except as expressly noted below, the following discussion of how an operator sets the data collection parameters is the same both for data collection and for preparing a system protocol that is to be saved for re-use.

To prepare the computer program for data collection either re-using a previously stored system protocol or by entering the data collection parameters directly without re-using a protocol, an operator selects a file menu 74 from the collection menu 64. From the file menu 74, the operator then selects a subject information menu 76. For data collection but not for protocol preparation, the operator enters information about the subject 38 into fields provided in the subject information menu 38 together with an MS-DOS name for the file in which the collected data will be stored and the length of time for which data is to be collected. Both for data collection and protocol preparation, the operator enters the number of data channels for which physiological signals are to be saved to the computer disk drives 44 at the subject information menu 76. Having entered this information and/or parameters at the subject information menu 76, the operator then returns to the file menu 74 by pressing either the "ESC" key on the

keyboard 52 or the right hand button on the mouse 54. If a previously stored data collection protocol is to be re-used, at the file menu 74 the operator selects a load menu 78, loads a previously stored system protocol, and returns to the file menu 74. The operator then returns to the collection menu 64 by pressing either the "ESC" key on the keyboard 52 or the right hand button on the mouse 54.

Having returned to the collection menu 64, an operator then selects an amps menu 80 to display, on a channel-by-channel basis, the current values assigned to parameters for the amplifiers in the EEG machine or polysomnograph 34. Usually the amplifiers in the EEG machine or polysomnograph 34 are set to a gain of 20,000. The operator uses keyboard 54 and/or the mouse 54 in assigning the proper values to these parameters. After the amplifier parameters for all the channels have been specified, the operator then returns to the collection menu 64.

From the collection menu 64, an operator then selects a montage menu 82, and from the montage menu 82 selects a collection montage menu 84. Strictly speaking, the collection montage menu 84 permits the operator to specify an association between a particular channel of binary data coming from the A/D converter 39 and a channel of data displayed on the video monitor 42 and recorded in a file on the disk drives 44. However, since the connection of the A/D converter 39 through the EEG machine or

polysomnograph 34 to the electrodes 36 on the subject 38 associates each channel of the A/D converter 39 with a particular physiological signal, the collection montage menu 84 actually permits the operator to specify an association between a particular physiological signal originating at the subject 38 and a channel of data displayed on the video monitor 42 and recorded in a file on the disk drives 44. In addition to specifying associations between a particular channel of data and a particular physiological signal, the collection montage menu 84 also permits an operator to specify that a particular data channel will display and record algebraic combinations of specified physiological signals from the subject 38, and/or that a particular data channel will display and record an average of signals from several electrodes 36 attached to the subject 38. After specifying the various data to be displayed on the video monitor 42 and recorded in files on the disk drives 44 at the collection montage menu 84, the operator returns to the collection menu 64 via the montage menu 82.

From the collection menu 64, an operator may then select a display format menu 86. If the operator does not specify a different display format using the display format menu 86, while the data is being collected the computer program displays the data on the video monitor 42 in a polygraph format such as that depicted in FIG. 3. In the polygraph format, data is displayed on a rectangular waveform display grid 88 in one thirty second swath

across almost the entire width of the video monitor 42. Displayed on the video monitor 42 in a rectangular area 92 immediately to the left of the waveform display grid 88 are data channel labels while voltage scaling factors appear in a rectangular area 94 immediately to the right of the waveform display grid 88. The data appearing in the waveform display grid 88 of the polygraph format appears much the same as it would appear in the traditional paper strip chart recording. At the display format menu 86, the operator may select other formats,, to be described below, in which the data will be displayed during collection. After having specified the format in which data will be displayed during collection, the operator returns to the collection menu 64.

After selecting the display format at the display format menu 86 and returning to the collection menu 64, an operator has completed specification of all the data collection parameters that would generally be provided by a system protocol. At this point the operator may save the protocol that has been specified by selecting, from the data collection menu 64, the file menu 74 followed by a save menu 96. At the save menu 96, the operator specifies that a system protocol is to be saved, assigns a MS-DOS file name for the new system protocol, and enters a label that describes the system protocol. After entering this data, the present data collection protocol is saved in an MD-DOS file on the computer disk drives 44 for subsequent re-use.

Having established the data collection parameters either by entering them directly or by re-using a system prior protocol, an operator now selects a calibration menu 98, and from that menu selects a calibration collection menu 102. The calibration collection menu 102 allows the operator to calibrate the various channels of the EEG machine or polysomnograph 34 and of the digital computer 32 that will be used in recording the physiological signals. In using the calibration collection menu 102, the operator successively supplies an analog electrical signal having a known amplitude to each input of the EEG machine or polysomnograph 34 while simultaneously entering data pertinent to the calibration procedure into the computer program. In this way the operator establishes a correlation between the amplitude of the physiological signals at the subject 38 and those displayed on the video monitor 42 and recorded in files on the disk drives 44.

After calibration has been completed, the operator commences data collection by selecting a start option in the data collection menu 64. A short time after data collection begins, that data will begin appearing on the video monitor 42 in format selected by the operator at the display format menu 86.

Having commenced data collection, an operator may still select various options from the data collection menu 64 while the computer system 30 records data from the subject 38. For example, the operator may choose a scale menu 112 from the data collection menu

64 which allows changing the vertical scale at which the various signals appear in the waveform display grid 88. If an operator wants to change the format in which the data is displayed during data collection, that may be accomplished by selecting the display format menu 86 from data collection menu 64.

If an operator wants to review previously recorded data while simultaneously continuing to record data, he may do so by selecting a time menu 114 from the collection menu 64 and specifying the time for which recorded data is to be replayed. The operator may also specify whether the replayed data is to occupy the entire data display area of the video monitor 42, or whether the replayed data is to appear in only a portion of that display area while the data being recorded continues to be displayed in the remainder of that area. The operator may choose to view the replayed data in any of the various display formats described herein below in connection with data analysis. Accordingly, during data collection an operator has full access to all of the various data analysis features provided by the computer program.

During data collection an operator may select an option on the data collection menu 64 that pauses data collection. When data collection is paused, the waveform display continues as does data storage on the computer disk drives 44 but the physiological signals are set to zero volts. If data collection has been paused, the operator may resume further data collection at any time by

pressing the ESC key on the keyboard 52 or the right button on the mouse 54. Similarly, the operator may also select an option on the data collection menu 64 that halts data collection entirely. Halting data collection may also be accomplished by pressing either the ESC key on the keyboard 52 or the right button on the mouse 54.

At any time during data collection, an operator may select a comment menu 116 from the data collection menu 64. The comment menu 116 allows the operator to enter a text message, and to correlate that comment with the thirty second time interval of a single epoch. As described in greater detail below, these comments may be used subsequently to locate and display data recorded for the epoch with which the comment is associated. Accordingly, associating comments with particular epochs in the recorded data effectively allows subsequent random access to the data during replay.

To prevent inadvertently changing parameters during data collection or inadvertently pausing or stopping data collection, the operator may select an option on the data collection menu 64 that causes the computer program to ignore input signals from both the mouse 54 and keyboard 52 except for one particular unique and obscure key combination on the keyboard 52. From the operator's perspective, this selection from the data collection menu 64 makes it appear as though the keyboard 52 and the mouse 54 have been locked. If during data collection the operator refrains from

entering the particular unique and obscure key combination on the keyboard 52 that unlocks both it and the mouse 54, they are automatically unlocked at the end of the previously specified data collection interval.

Data Analysis

An operator of the sleep analysis digital computer system 30 may analyze previously collected data in five different ways. Thus, by selecting the appropriate options from various menus an operator may display the raw data as it was collected, analyze raw data for sleep stage scoring and to identify respiratory disturbances, display and interpret the results of sleep scoring, save the scoring results to the disk drives 44, and retrieve prior scoring results from the disk drives 44.

To display the raw data as it was collected, an operator first selects the data analysis menu 66 from the main menu 62 which causes the polygraph format display, illustrated in FIG. 3, to appear on the video monitor 42. As depicted in FIG. 3, appearing in a horizontal menu selection bar 118 across the top of the video monitor 42 are the various menu selections that are allowed from the data analysis menu 66. In displaying the raw data, from the data analysis menu 66 the operator then selects the file menu 74 followed by the load menu 78 as illustrated in FIG. 2. At the load menu 78, an operator specifies the particular file of previously

collected data to be loaded. Having thus loaded the raw data, similar to data collection there are two ways an operator may prepare the computer program for data analysis. The first way is to interactively set up a display protocol by reviewing each program option affecting the display of sleep data, adjusting parameter values if necessary. The second way of preparing the computer program to analyze previously collected data is to re-use a previously stored display protocol.

To load a previously stored display protocol, while at the load menu 78 an operator requests that a file containing the desired display protocol be loaded into the digital computer 32. Except as expressly noted below, the following discussion of how an operator interactively sets the data analysis parameters is the same both for performing data analysis and for preparing a display protocol that is to be saved for re-use.

In interactively preparing the computer program for data analysis or preparing a display protocol, if the display format presently appearing on the video monitor 42 is not that desired, an operator first selects the display format menu 86 from the data analysis menu 66. At the display format menu 86, the operator may choose among several different display formats that one in which the data will be displayed.

In the instance of the polygraph format illustrated in FIG. 3, which can be selected at the display format menu 86, the

operator may specify a number of signal channels up to a maximum of thirty-two to appear on the video monitor 42. Furthermore, the operator may select among three different modes in which new data will replace that presently being displayed: normal polygraph mode, scroll polygraph mode and page polygraph mode. In the normal polygraph mode, new data overwrites the earlier data from left to right across the waveform display grid 88. In the scroll polygraph mode, new data appears along the right edge of the waveform display grid 88 while the earlier data moves progressively away from the right edge toward the left edge thereby effectively pushing the oldest data off the left edge of the waveform display grid 88. Thus, the visual appearance of the scroll polygraph mode of display is similar to the operation of the traditional multi-channel ink-on-paper recording. In the page polygraph mode, the data displayed in the entire waveform display grid 88 is entirely overwritten all at one time.

In the polygraph format depicted in FIG. 3, the time base for the display in seconds per major division across the width of the video monitor 42 appears in a rectangular box 122 near the lower right corner of FIG. 3. As depicted in FIG. 3, there are three seconds per major division in the polygraph format display. Accordingly, regardless of which of these three display modes is selected in the polygraph format, a thirty second epoch of all of the specified physiological signals appears across the width of the

waveform display grid 88. Also displayed in a rectangular box 124 at the lower right corner of the video monitor 42 is the number of the epoch which is currently being displayed. Immediately below the epoch number in the box 124 is a time display 126 of the time for the epoch presently appearing on the video monitor 42.

Appearing at the bottom of the screen immediately below the waveform display grid 88 are paging icons 132, 134, 136 and 138. Using the mouse 54 to select one of the paging icons 132 through 138, or keyboard equivalents to the icons 132 through 138, an operator may page either forward or backward through the data file. The left pointing icons 132 and 136, or their keyboard equivalents, move the data displayed on the video monitor 42 toward the beginning of the raw data, while right pointing icons 134 and 138, or their keyboard equivalents, move the displayed data toward the end of the raw data. The single arrowed icons 136 and 138, or their keyboard equivalents, move one epoch for each successive selection while the double arrowed icons 132 and 134 cause continuous and uninterrupted paging through successive epochs in the raw data file. The keyboard equivalent of the icon 132 is the shifted left pointing arrow. Analogously, the keyboard equivalent to the icon 134 is the shifted right pointing arrow. The un-shifted left pointing arrow on the keyboard is equivalent to the icon 136 while the un-shifted right pointing arrow on the keyboard is equivalent to the icon 138.

Another display format that may be selected from the display format menu 86 is a staging display format illustrated in FIG. 4. In the staging format, a single thirty second epoch of the three channels of the physiological signals that are the basis for sleep stage scoring, i.e. EEG, EOG and EMG, are displayed on the video monitor 42. This single thirty second epoch of data is displayed in three successive horizontal segments or swaths 142 of waveform display grids, one below the other, across the width of the video monitor 42. Appearing in a rectangular box 144 at the left end of each swath 142 are labels identifying the EEG, EOG and EMG signals. Analogous to the rectangular area 94 in the polygraph display format, appearing in a rectangular box 146 at the right end of each swath 142 are the voltage scaling factors for each of the physiological signals. Each of the swaths 142 displays one-third of the thirty second epoch, i.e. ten seconds. Accordingly, each major division across the width of the video monitor 42 displays a one second interval of the physiological signals as appears in the rectangular box 122.

FIG. 5 illustrates a display format used in respiratory analysis that may be selected from the display format menu 86. Similar to the staging display format illustrated in FIG. 4, the respiratory display format of FIG. 5 presents three successive horizontal segments or swaths 142 of waveform display grids, one below the other, across the width of the video monitor 42.

Displayed in each of the swaths 142 are four physiological signals identified in rectangular boxes 152 located at the left end of each of the swaths 142, i.e. air flow, thorax and abdomen respiratory effort channels, and blood-oxygen saturation. As with both the polygraph and staging display formats, voltage scaling factors for each of the signals appear in rectangular boxes 146 at the right end of each swath 142. In the respiratory display format, each swath 142 displays two minutes of the four physiological signals thereby presenting a total of six minutes of data on the video monitor 42. Accordingly, a time base of ten seconds per major division appears in the rectangular box 122. Appearing above the left end of each swath 142 is a number 154 for the first thirty second epoch in each swath 142. Above the right end of each swath 142 appears a number 156 that indicates the time of the data appearing at the right end of each swath 142.

If automatic respiratory analysis is active, event markers in the respiratory display format indicate the presence of respiratory disturbances. Events are marked with an alphabetic letter 158 from which a bar 162 extends horizontally to the right. The color of both the letter and the bar displayed on the color video monitor 42 indicates the nature of the respiratory disturbance: red for apnea or magenta for hypopnea. The alphabetic letter indicates the type of the apnea or hypopnea: "C" for central, "O" for obstructive, and "M" for mixed. The length of the line extending

from the alphabetic letter corresponds to the length of the respiratory disturbance.

FIG. 6 illustrates a rectangularly shaped respiratory disturbance log 168 that may be selected from the display format menu 86. The respiratory disturbance log 168 is superimposed over a portion of other displays such as the respiratory display format illustrated in FIG. 5. The following table summarizes the data presented in the eleven vertical columns across the width of the respiratory disturbance log 168.

Column Id	Data
#	The number assigned sequentially to each event
Epch	The number of the epoch in which the respiratory disturbance occurred
Time	The elapsed time, from the beginning of the data file, at which the respiratory disturbance occurred
Len	The duration of the respiratory disturbance in minutes
Afct	The presence or absence of an artifact
A/H	The nature of respiratory disturbance: "AP" for apnea and "HY" for hypopnea
Type	The type of respiratory disturbance: "C" for central, "O" for obstructive and "M" for mixed
Arsal	Whether arousal accompanied the respiratory disturbance (Y) or arousal did not accompany the respiratory disturbance (N)
Stg	The sleep stage assigned to the epoch in which the respiratory disturbance occurred
SaO2	The percent blood-oxygen saturation expressed as a minimum baseline value over the minimum value during the respiratory disturbance
A/M	Whether the respiratory disturbance was scored automatically (A) or manually (M)

Selecting the respiratory disturbance log display format also activates several function keys on the keyboard 52. Repetitively pressing function key 3 allow moving the respiratory disturbance log 168 to either the top, middle or bottom of the video monitor. By moving the respiratory disturbance log 168 vertically on the video monitor 42, an operator may view any part of the data

displayed in the background display format without removing the respiratory disturbance log 168. Highlighting a particular event listed in the respiratory disturbance log 168 using the mouse 54 and then pressing function key 10 causes the background display format to present the physiological signals at the time of the highlighted event.

FIG. 7 illustrates another display format, analogous to the display format of FIG. 4, that also has three horizontal segments or swaths 142 of waveform display grids, one below the other, across the width of the video monitor 42. However, rather than providing an expanded display of the raw data for a single epoch as in FIG. 4, FIG. 7 displays the raw data for three epochs at different times as indicated by numbers 172 located above the right end of each of the swaths 142. Analogous to the display format of FIG. 5, the number 154 for each of the epochs appearing on the video monitor 42 appears above the left end of each of the swaths 142. Using the display format of FIG. 7, an operator may compare physiological signals for arbitrarily selected epochs.

Having selected the desired display format, after returning from the display format menu 86 to the data analysis menu 66 the operator then selects the montage menu 82 followed by a display montage menu 176 as depicted in FIG. 2. At the display montage menu 176, the operator specifies the various channels of physiological signals.that are to be displayed, the order of the

physiological signals from top to bottom on the display format, together with the label appearing to the left of each waveform that identifies it. When specifying the montage for the staging and respiratory display formats, care must be exercised to insure that the proper channel of physiological data is specified so automatic sleep scoring and respiratory analysis will operate properly. The proper assignment of the physiological signals is described below in connection with automatic sleep scoring.

After selecting the display format at the display format menu 86 and specifying the various physiological signals at the montage menu 82, the operator has completed specifying all the data analysis parameters that would generally be provided by a display protocol. At this point, an operator may save the display protocol that has been developed by selecting, from the data analysis menu 66, the file menu 74 followed by the save menu 96. At the save menu 96, the operator specifies that a display protocol is to be saved, assigns a MS-DOS file name for the new display protocol, and enters a label that describes the display protocol. After entering this information, the present display protocol is saved in an MD-DOS file on the computer disk drives 44 for subsequent re-use.

Having established the data analysis parameters either by entering them directly or by re-using a prior protocol, the computer system 30 is now ready to display previously collected data for analysis. An operator causes data to be displayed on the

video monitor 42 by moving through the previously collected raw data that is now stored on the disk drives 44. There are several alternative ways an operator may specify the time of the recorded raw data to be displayed.

One way of displaying the recorded data is to select the time menu 114 from the data analysis menu 66. At the time menu 114 the operator enters the number of the desired epoch and shortly thereafter the physiological signals for that epoch are displayed on the video monitor 42 in the previously selected display format. Alternatively, an operator can use the paging icons 132 and 134, or their keyboard equivalents, to page continuously either backward or forward through the recorded data. An operator may stop continuous paging either by pressing the ESC key on the keyboard 52 or the right button on the mouse 54. Analogously, an operator can page backward or forward through the data one epoch at a time using the paging icons 136 or 138 or their keyboard equivalents.

If comments have been associated with the recorded data, an operator can use them to move directly to the data with which the comment is associated. To obtain such direct access to the data the operator selects the comment menu 116 from the data analysis menu 66. At the comment menu 116, the operator selects a position option and a box appears on the video monitor 42 listing each of the comments and their respective temporal location within the recorded data. The operator then selects the desired comment after

which the recorded data for the epoch with which that comment is associated appears on the video monitor 42.

To adjust the displayed height of the waveforms, an operator selects the scale menu 112 from the data analysis menu 66. Having selected the scale menu 112, the operator then select the channels for the physiological signals whose scale is to be raised or lowered. Raising the scale increases the height of the selected physiological signal while lowering the scale decreases the waveform's height.

At any time during the display of previously recorded data, an operator may review any textual comments added to the data during data collection or during a prior data analysis session, or insert a textual comment to be associated with previously recorded data by selecting the comment menu 116 from the data analysis menu 66. Such comments are displayed in the lower right corner of the video monitor 42 when the data is displayed for the epoch with which the comment has been applied.

In addition to adding comments at the comment menu 116, an operator may also delete comments. In deleting a comment, a box analogous to the respiratory disturbance log 168 listing each comment and its temporal location within the data file appears on the video monitor 42 over the data display. The operator then uses the mouse 54 to highlight the comment to be deleted.

Scoring

In addition to displaying the raw physiological data as described above, such data can be automatically scored for sleep staging and for respiratory analysis by selecting a scoring menu 192 from the data analysis menu 66. Moreover, sleep stages can be scored manually using a manual scoring mode, and previously scored sleep stages can be overwritten using a revise scoring mode. However, before raw physiological data may be scored, it must first be loaded and displayed on the video monitor 42 for data display as described above. Furthermore, because the automatic sleep staging and respiratory analysis require a pre-established assignment of particular physiological signals, e.g. EEG, EMG, EOG, airflow, etc., to particular positions in the staging display format and in the respiratory display format prior to automatic analysis, those assignments should be checked by selecting the display montage menu 176 from data analysis menu 66 via the montage menu 82 prior to performing automatic analysis.

In particular, for automatic sleep staging the EEG channel of physiological data must be assigned to the first position highest in the swaths 142 of the staging display format illustrated in FIG. 4. Similarly, the EOG channel must be assigned to the second position in the middle of the swaths 142 while the EMG channel must be assigned to the third position at the bottom of the swaths 142 of the staging display format.

Analogously, for automatic respiratory analysis the air flow channel of physiological data must be assigned to the first position highest in the swaths 142 of the respiratory display format illustrated in FIG. 5. The second and third positions about the middle of the swaths 142 must be assigned to channels of physiological data indicative of respiratory effort. Typically the second position indicates thorax effort while the third position indicates abdominal effort. Finally, the oxygen saturation (SaO2) must be assigned to the fourth position lowest on the swaths 142 of the respiratory display format.

In addition to confirming the proper assignment of the respective physiological signals to the appropriate positions on the staging and respiratory display formats, suitable values must also be assigned to automatic analysis parameters by selecting a parameters menu 194 from the data analysis menu 66. FIG. 8 illustrates a matrix display for the automatic sleep scoring parameters that an operator uses in assigning values to those parameters. The display of FIG. 8 allows an operator to specify horizontal rows of parameters used in automatically identifying each of the following sleep scoring waveform events; alpha, spindle, slow wave, K complex REM and high EMG. Thus the matrix display of FIG. 8 includes an alpha row 202, a spindle row 204, a slow wave row 206, a K complex row 208, REM row 212, and a high EMG row 214.

All six different types of events, i.e. alpha, spindle, slow wave, K complex REM and high EMG, are characterized at least in part by a threshold voltage amplitude parameter appearing in a vertical column 222 of the matrix display of FIG. 8. In addition to the voltage amplitude parameter in the column 222, the alpha row 202, spindle row 204, slow wave row 206, K complex row 208 and REM row 212 events are also characterized by a lower frequency parameter and an upper frequency parameter appearing respectively in vertical columns 224 and 226 of the matrix display of FIG. 8. In addition to the voltage amplitude parameter in the column 222 and the frequency parameters in the columns 224 and 226, the alpha row 202 and spindle row 204 events are also characterized by a regularity parameter also appearing in a vertical column 228 of the matrix display of FIG. 8.

A value must be specified for each of the parameters at the respective intersections of the horizontal rows 202, 204, 206, 208, 212 and 214 with the vertical columns 222, 224, 226 and 228 in which parameters appear in FIG. 8. Revised values for these parameters may be entered by choosing the appropriate entry appearing in a parameter editing field 232 displayed at the right of FIG. 8 which duplicates the parameter display in the intersections of rows 202 through 214 with columns 222 through 228. Each parameter to be changed is selected using the mouse 54 or the keyboard 52 and then a new numeric value is entered using the

keyboard 52. Thus, while an operator is specifying new values for the various parameters in the editing field 232 to be used in the automatic scoring of the raw data, the presently specified values of the parameters continue to appear at the intersections of the horizontal rows 202, 204, 206, 208, 212 and 214 with the vertical columns 222, 224, 226 and 228. In addition to providing a work area in which the present values of the automatic analysis parameters may be edited, the editing field 232 may also be used to display other sets of automatic analysis parameters read from the disk drives 44.

After an operator has specified the values for the automatic analysis parameters in the editing field 232 either by reading a set of previously saved parameters, by entering them directly, or by a combination thereof, the operator then requests that the parameter values in the editing field 232 be transferred to the intersections of the horizontal rows 202, 204, 206, 208, 212 and 214 with the vertical columns 222, 224, 226 and 228. By transferring the parameters from the editing field 232 to the intersections of the rows and columns the operator makes them the values that will be used in automatically scoring the raw data. As with the system protocols for data collection and display protocols for data analysis, at the parameters menu 194 sets of scoring parameters may also be saved on the disk drives 44 for re-use at some subsequent time when they are then re-loaded.

For the four different types of EEG events, i.e. alpha, spindle, slow wave and K complex, the parameters respectively specified in the rows 202 through 208 are used independently of each other in automatically identifying such events. Conversely, the parameters in the rows 212 and 214 are used together in automatically identifying REM events.

To identify alpha, spindle, slow wave, K complex and REM vents, the raw physiological data is processed exploiting the analysis technique described the paper entitled "A Practical Method for Automatic Real-Time EEG Sleep State Analysis" by Lim and Winters, which was published at pages 212-220 in the April 1980 issue of the IEEE Transactions on Biomedical Engineering, Vol. BME-27, No. 4 ("the Lim and Winters paper"). This paper is incorporated by reference as though fully set forth here. After vents have been identified in the raw data, those identifications are used in accordance with the criteria of the Rechtschaffen and Kales sleep scoring system to characterize the different stages of sleep based upon the raw data event identification.

In accordance with the Lim and Winters paper, the occurrence of events characterized by a high frequency EEG signal, i.e. alpha and spindle, are identified by analyzing peak values in the raw EEG data. In performing this analysis, each one-half second interval of the raw EEG signal is processed to determine the time intervals between successive peak values in the raw EEG data. If the

interval between the peak values is much too short, then such an interval is eliminated from further analysis as being due to some artifact. The intervals determined by this process are then further analyzed to determine the mean frequency throughout the ne-half second interval and also the highest and lowest momentary frequency during that interval. If the amplitude and mean frequency throughout the one-half second interval satisfy the amplitude threshold and frequency limits respectively specified for either an alpha or spindle event, then the difference between the highest and lowest momentary frequency throughout the one-half second interval is compared with the regularity parameter. A value of zero for the regularity parameter assures the acceptance of each event which satisfies the amplitude threshold and frequency limits. Conversely a value of five for the regularity parameter assures the rejection of all events which satisfy the amplitude threshold and frequency limits. Increasingly higher values of the regularity parameter between its limits of zero and five cause the rejection of events having progressively smaller differences between the highest and lowest momentary frequency.

Also in accordance with the disclosure of the Lim and Winters paper, events characterized by a low frequency EEG signal, i.e. slow wave and K complex EEG events and REM events, are identified by analyzing zero crossings respectively in the raw EEG data or raw EMG data. However, before these signals are analyzed to identify

such events, the data are first filtered and smoothed to eliminate high frequency components. After filtering and smoothing, the zero crossings of the respective signals are analyzed to identify events satisfying both the specified amplitude threshold and frequency limits. While the slow wave and K complex EEG events are identified solely by satisfying the criteria specified by the parameters in rows 206 and 208 of FIG. 8, REM events are identified only if the criteria specified by the parameters in row 212 are satisfied during intervals in which there is a low EMG signal. Consequently, ven though the raw REM data has a sufficiently high amplitude and has a frequency lying within the specified frequency range, the computer program will not score that data as a REM event unless the EMG data is lower than the threshold value.

Automatic respiratory analysis identifies events of respiratory dysfunction in the raw respiratory data and assigns those events to the respiratory disturbance log illustrated in FIG. 6. In automatically identifying a respiratory disturbance, the computer program compares the present airflow with a "moving window" baseline mean amplitude for airflow. If the present airflow drops 20% below the baseline value while remaining above 50% of the baseline value and remains within the range of 20% to 50% below the baseline value for 10 seconds, then an apnea event has begun. Alternatively, if the present airflow drops 50% below the baseline value and remains below that level for 10 seconds,

then a hypopnea event has begun. An apnea event or a hypopnea event ends when the present airflow returns to the baseline value existing prior to the event's commencement.

Events of apnea or hypopnea are classified as central, obstructive or mixed based on data in either of the respiratory effort data channels, i.e. the thorax or the abdominal data. If the muscles of either the thorax or the abdomen are inactive throughout the event, then it is classified as central. If the muscles are active throughout the event, then it is classified as obstructive. If the muscles are partially active during the event, then it is classified as mixed.

To activate automatic scoring of sleep stages and/or respiratory analysis, an operator selects the scoring menu 192 from the data analysis menu 66 and then specifies either an automatic stage scoring mode or an automatic respiratory mode, or both. The present status of these modes is respectively indicated in rectangular boxes 242 and 244 located in the upper right hand corners of various display formats such as the polygraph display format illustrated in FIG. 3, the staging display format illustrated in FIG. 4, and the respiratory display format illustrated in FIG. 5. If automatic sleep staging is selected, the word "AUTO" appears in the box 242. And if automatic respiratory analysis has been selected, the word "AUTO" appears in the box 244.

With automatic sleep staging or automatic respiratory analysis selected as described above, each epoch of raw physiological data that appears on the video monitor 42 is scored automatically. Moving through the data as described above in connection with data analysis causes each epoch appearing on the video monitor 42 to be scored. As depicted in FIGs. 3, 4 and 5, characters and numbers displayed in a horizontal stage scoring bar 248 across the top of the screen immediately beneath the menu selection bar 118 and immediately above the waveform display grid 88 or the uppermost swaths 142 indicates the sleep stage score for the epoch. The following table lists the characters and numbers that may appear in the stage scoring bar 248 together with the corresponding sleep stage.

Character or Number	Sleep Stage
M	Movement
W	Waking stage
R	Rapid Eye Movement ("REM") stage
U	Undefined
1	Sleep Stage 1
2	Sleep Stage 2
3	Sleep Stage 3
4	Sleep Stage 4

By selecting a "LEARNING" option in the data analysis menu 66, an operator may "teach" the data analysis portion of the computer program how to score the raw data. This process is repeated one after the other to "teach" the data analysis portion of the computer program suitable analysis parameters for each of the various different types of events, i.e. alpha, spindle, slow wave, K complex, REM and high EMG. To prepare the data analysis portion of the computer program for "learning" how to score raw data, the operator initially specifies comparatively relaxed parameters, i.e. a low amplitude in column 222, a wide frequency range in columns 224 and 226, and a regularity of zero in column 228. The data analysis program then scores one epoch for alpha events, usually the first epoch in the raw data because that epoch will usually contain alpha events. After scoring an epoch for alpha, the data analysis program then displays the results and allows the operator to successively specify whether each event has been identified correctly or incorrectly. After all the events in an epoch have been classified as being correctly or incorrectly identified, the operator can decide to score another epoch or terminate learning for this particular type of event. By this process, the data analysis portion of the computer program collects a set of prototypical events whose scoring is acceptable to the operator and a set of events which the operator has rejected.

Using an operator's classification of events, the computer program then adjusts the automatic analysis parameters to conform with that classification. This adjustment of the automatic analysis parameters is possible because the operator's acceptance and rejection of events effectively compiles amplitude and mean frequency data both for the accepted and for the rejected events. The computer program then uses this data to assign values for those parameters that are compatible with the operator's classification of the events. Two different methods may be employed to assign these values to the parameters using the data collected by the computer program, a simpler one and a slightly more complicated one.

The simpler method for assigning values to the parameters used for event identification employs only the data for the accepted events. In this simpler method, the minimum amplitude for the accepted events, the minimum mean frequency for those events and the maximum mean frequency for those events are assigned as the values for the respective parameters in columns 222, 224 and 226.

The more complicated method for assigning values to the parameters used for event identification uses both the data for the accepted events and for the rejected events. This more complicated method determines the range of overlapping values for each parameter between the accepted and the rejected events. The value of that parameter is then set equal to the value at the center of

the overlapping range. Thus, for the amplitude parameter, the value assigned to column 222 is one-half of the minimum value of the accepted events plus the maximum value of the rejected events. For the assignment of the lower and upper frequency limits respectively in columns 224 and 226, the rejected events are divided into those having a mean frequency lower than the average of the accepted events and those having a mean frequency higher than the average of the accepted events. The value then assigned to the lower frequency limit in column 224 is one-half of the minimum value of the mean frequency for the accepted events plus the maximum value of the mean frequency for the rejected events having a mean frequency lower than the average for the accepted events. Similarly, the value then assigned to the upper frequency limit in column 226 is one-half of the maximum value of the mean frequency for the accepted events plus the minimum value of the mean frequency for the rejected events having a mean frequency higher than the average for the accepted events.

In either of these ways, data from the operator's event classification are used to assign values for the amplitude and the lower and upper frequency parameters that distinguish between those events accepted by an operator and those rejected by the operator. The parameters that the computer program has "learned" in this way are then used to score the raw data in substantially the same way as the operator would score it. Thus, an operator may interactive-

ly "teach" the computer the particular way in which a subject's sleep is to be scored.

As an alternative to scoring each epoch as it is displayed on the video monitor 42, the entire file of raw physiological data may be automatically scored if so specified at the scoring menu 192. Also, by specifying an appropriate starting epoch number and ending epoch number for the raw physiological data to be scored, automatic scoring may be restricted to continuous segments that are only a fraction of the raw data.

During automatic scoring of an entire data file or a segment of a file, the display presented on the video monitor 42 does not change. Conversely, continuously paging through the data by means of the paging icons 132 and 134, or their keyboard equivalents, causes the scoring of each epoch to appear immediately on the video monitor 42.

In addition to allowing the specification of automatic sleep stage scoring, the scoring menu 192 also permits selecting manual sleep stage scoring. If manual sleep stage scoring is selected, the word "MANUAL" appears in the box 242 together with an array of icons consisting of boxed letters and numbers, not illustrated in FIGs. 3, 4 or 5, that are located along the right hand edge of the video monitor 42. An operator can select the appropriate one of these icons with the mouse 54 to manually score an epoch. Alternatively, an operator may score the epoch by pressing the key

on the keyboard that corresponds to the letter or number displayed in the icon. After a score has been specified for an epoch, all successive epochs displayed on the video monitor 42 are assigned that same score until the operator selects a different score for the epoch then being displayed. If at the scoring menu 192 an operator selects a revise sleep scoring mode rather than the automatic or manual sleep scoring modes, the score previously assigned to epochs may be changed in the same manner as that described above for manual scoring. As with sleep staging, respiratory disturbances may also be scored manually and any prior scoring may be revised.

In addition to the display formats described above in connection with data analysis, the display format menu 86 provides other display formats that are specially adapted to display the results of sleep scoring and respiratory analysis. The first of these display formats is the hypnogram display format illustrated in FIG. 9. The hypnogram display format presents sleep stage scoring as a function of time. Sleep stages are indicated along a vertical axis 262 by the same characters and numbers as those described above in connection with the stage scoring bar 248 except for the "U," undefined, score. Elapsed time (in hours) is indicated along a horizontal time axis 264. A plurality of vertical line segments 266 extending upward from the time axis 264 indicate the stage of sleep occurring during each epoch.

In the hypnogram display format four cursor icons 272, 274, 276 and 278, located near the bottom of the display on the video monitor 42, or their keyboard equivalents, move a vertical cursor 282 back and forth along the horizontal time axis 264 in the same manner as the paging icons 132 through 138. Displayed in the hypnogram display format immediately to the right of the horizontal time axis 264 and slightly above the time display 126 for the current cursor position appears a sleep stage score 286 for the present cursor position.

Another display format that is specially adapted for displaying the results of scoring which may be selected from the display format menu 86 is the summary display format illustrated in FIG. 10. The particular summary display format illustrated in FIG. 10 presents in three separate rectangular areas extending across the width of the video monitor 42 and positioned vertically along its height a combination of data taken from the hypnogram display format, from the respiratory disturbance log display format, and the respiratory display format. As depicted in FIG. 10, the summary display format includes a unique menu presented in the menu selection bar 118.

The "Window Setup" command in the summary display format menu allows an operator to adjust the type of plot that appears in each of the three areas, the time base along horizontal time axes 264a, 264b and 264c respectively displayed near the bottom of each area,

and the colors used in the hypnogram plot. The "Window Setup" command also allows unlocking vertical cursors 282a, 282b and 282c so that they either move independently within each of the three areas or locking them so they move in unison across all three areas.

The "Set File Position" command in the summary display format allows an operator to set the active epoch to the present cursor position. Thus, having set the file position at a particular epoch in the summary display format, the raw data for that epoch will be displayed automatically if one of the display formats such as the polygraph, staging or respiratory display formats are then selected to replace the summary display format.

The "Change Active Window" command in the summary display format allows selecting which of the cursors 282a, 282b or 282c in three areas will control the "Set File Position" command. This command also allows specifying which of the cursors 282a, 282b or 282c will move in response to commands from cursor icons 272 through 278, or their keyboard equivalents. An arrow 292 located to the left of one of the horizontal axes 264a, 264b or 264c indicates which area is presently active.

Displays located immediately to the right of the of each of the axes 264a, 264b and 264c respectively present information pertinent to the plot displayed along the corresponding axis 264a, 264b or 264c. Accordingly, displayed to the right of the axis 264a

along which a hypnogram is plotted are a time display 126a for the position of the cursor 282a along the axis 264a and the sleep stage score 286 for that position of the cursor 282a.

A respiratory disturbance plot appears immediately below the hypnogram in the particular summary display format illustrated in FIG. 10. This respiratory disturbance plot displays apneas, hypopneas and arousals along the horizontal time axis 264b. In the respiratory disturbance plot, a plurality of vertical line segments 296 are displayed to the right along the axis 264b from the words "Apnea" and "Hypopnea," that are located immediately to the left of a vertical axis 298. Each vertical line segment indicates the occurrence of a respiratory disturbance at the corresponding time and the type of disturbance that occurred. The vertical position of each of these vertical line segments with respect to the words "Apnea" or "Hypopnea" indicates the time within the epoch at which the disturbance occurred. The color of the line segment indicates whether the respirator disturbance was central (red), obstructive (blue) or mixed (green). The length of the vertical line segments represent the duration of the respiratory disturbance. If a respiratory disturbance is accompanied by arousal, that will be indicated by the presence of a vertical line segment at the appropriate location along the axis 264 to the right of the word "Arousal."

Similar to the hypnogram, a time display 126b on the respiratory disturbance plot immediately to the right of the axis 264b displays the time for the position of the cursor 282b along the axis 264b. Immediately above the time display 126b appear three encodings 302 indicating the type of disturbances(s) that occurred during the epoch at which the cursor 282b is presently located. Each encoding 302 is made up of three alphabetic characters separated by "/" punctuations. The vertical position of the encodings indicates their respective order of occurrence within the epoch with the earliest respiratory disturbance encoded at the top and the latest one encoded at the bottom. The first character in each encoding indicates whether the disturbance was a apnea (A) or a hypopnea (H). The second character in each encoding indicates whether the disturbance was central (C), obstructive (O) or mixed (M). The third character in each encoding indicates whether the disturbance was accompanied by arousal (Y) or was not accompanied by arousal (N).

A blood oxygen saturation plot appears immediately below the respiratory disturbance plot in the particular summary display format illustrated in FIG. 10. Extending horizontally to the right of a vertical axis 306 that represents blood oxygen saturation, i.e. SaO2, increasing from 0% to 100%. appear a plurality of vertical line segments 308. Each vertical line segment presents the minimum and maximum oxygen saturation within an epoch. The

vertical line segment's position along the axis 264c correlates the epoch's time.

Similar to both the hypnogram and the respiratory disturbance plots, a time display 126c on the oxygen saturation plot immediately to the left of the axis 264c displays the time for the position of the cursor 282c along the axis 264b. Immediately above the time display 126c appears a minimum blood oxygen saturation 312 for the epoch at which the cursor 282c is positioned. And immediately above the minimum blood oxygen saturation 312 appears a maximum blood oxygen saturation 314 for that same epoch.

FIG. 11 illustrates another display format, which may be selected from the display format menu 86, that displays several different physiological signals occurring at different times in the raw data. Thus two different swaths 142 of respiratory analysis raw data signals, similar to those described previously in connection with FIG. 5, are displayed for two relatively short time intervals that are widely separated in time. In this particular illustration of this display format, beneath the two swaths 142 appears a blood oxygen saturation plot similar to that described previously in connection with FIG. 10. A pair of vertical cursors 322a and 322b on the blood oxygen saturation plot identify the time interval for which the respiratory analysis raw data signals are displayed in the uppermost swath 142.

FIG. 12 as well as FIG. 11 illustrate display formats in which two different physiological signals are displayed over differing durations. In the particular display illustrated in FIG. 12, two horizontal swaths 142 of the EEG, EOG and EMG physiological signals are displayed in the same scale as that illustrated in the display format illustrated in FIG. 4. As with FIG. 11, in this particular illustration of this display format beneath the two swaths 142 appears a blood oxygen saturation plot. A pair of vertical cursors 322a and 322b on the blood oxygen saturation plot, spaced so closely together as to be almost indistinguishable, identify the time interval for which the physiological signals are displayed in the two swaths 142. Display formats such as those illustrated in FIGs. 10 through 12 are particularly useful in correlating respiratory disturbances with the various physiological signals such as SaO2, sleep staging, arousal and the EEG and EMG signals.

In addition to the various analyses described above, the computer program will cumulate the time for each different type of event through out a night's sleep. The computer program will also count the number of times each different type of event occurs through a night's sleep. A graphic display of either or both of these cumulative data can be selected from the display format menu 86 and a character display of their numerical value may be obtained from the scoring menu 192.

Automatic Scoring Parameter Selection

The computer program may also automatically select the parameters used for event identification described above in connection with FIG. 8. Thus an operator may enter certain physical characteristics for the subject 38 such as age, medication, prior sleep dysfunctions, diagnostic categories both physiological and psychological, and stress level. The computer program will then use these characteristics to select an initial, trial data analysis protocol from a library of such protocols. The parameters selected in this manner are then used in a trial scoring of a portion of the raw data either in the "learning" mode described above or directly using automatic scoring. If this trial is performed using automatic scoring, then the computer program may compare the overall results of that scoring with pre-established criteria to determine if those results are reasonable. For example, scoring must begin and end in the awake state. If the initial trial scoring parameters fail to produce this result different trial parameters must be selected. Similarly, if the trial scoring results in a hypnogram that reaches stages 1 and 2 of sleep but never gets to stage 4 sleep, this indicates that the trial parameters for identifying slow wave events need to be altered so the scoring results in stage 4 sleep. Similarly, if the scoring shows an excessive amount of stage 4 sleep, then the slow wave and alpha parameters must also be altered to decrease the

amount of stage 4 sleep. If the trial scoring results in an excessive amount of stage 2 sleep, then the parameters for spindle, K complex and alpha must be altered to decrease the amount of stage 2 sleep.

Snoring

During data collection, a channel of physiological data may be collected from a microphone present in the room the subject 38, or by any other sensor which responds the generation of perceptible, audible sound produced by the subject 38. Since the strength of the signal produced by such a sensor itself constitutes a perceptible sound signal associated with the generation of audible sound by the subject 38, the mere amplitude of such a signal reveal the occurrence of snoring. Consequently, either the waveform produced by the sensor itself or only the envelope of that waveform may be included among the collected data. Moreover, this perceptible sound signal may only be recorded during epochs in which it exceeds a pre-established threshold. If the waveform of the audible sound is to be recorded directly, then that signal should be sampled at a frequency of 15 KHz. Alternatively, if only the envelope of the audible sound signal is to be recorded, a sampling rate of approximately 200 Hz is adequate.

By recording the audible sound which occurs during snoring, it becomes possible to analyze the causes of snoring and to

determine whether it is merely an annoyance or hazardous to a subject 38. For example, snoring which is hazardous to a subject 38 may precede or correlate with events of apnea or hypopnea, or to reduction of the SaO2 level. Such correlations between snoring and other events may be easily established after the raw physiological data has been scored for the stages of sleep and for respiratory disturbances. The correlation between snoring and other events may either be identified analytically or using graphical displays of the recorded physiological signals and/or of their scoring.

Topographic Display of EEG Signals

Since the apparatus and computer program disclosed herein is capable of recording far more channels of data than are usually required merely for sleep analysis, by employing a larger number of EEG sensors 36 secured to the head of the subject 38 and recording the data from such sensors, the sleep analysis techniques disclosed above may be effectively combined in a single computer program with brain electrical activity analysis and mapping. Techniques for such brain electrical activity analysis and mapping which are also compatible with the sleep staging and respiratory analysis disclosed herein are described in U.S. Patents No.s 4,649,482, 4,744,029 and 4,862,359 which are all assigned to the assignee of the present application. Accordingly, those patents

are hereby incorporated by reference as though fully set forth here.

Although the present invention has been described in terms of the presently preferred embodiment, it is to be understood that such disclosure is purely illustrative and is not to be interpreted as limiting. Consequently, without departing from the spirit and scope of the invention, various alterations, modifications, and/or alternative applications of the invention will, no doubt, be suggested to those skilled in the art after having read the preceding disclosure. Accordingly, it is intended that the following claims be interpreted as encompassing all alterations, modifications, or alternative applications as fall within the true spirit and scope of the invention.

<u>What Is Claimed Is</u>:

1. An apparatus for analyzing physiological signals recorded from a sleeping subject comprising:

a. signal association means for identifying several physiological signals among those recorded;

b. display means for selecting among various different graphic display formats a particular display format in which recorded physiological signals are displayed, and for displaying such signals;

c. event identification means for establishing parameters which characterize a specific waveform in the recorded physiological signals that identifies a particular type of event in those signals, said event identification means including:

i. initialization means for establishing initial values for the parameters;

ii. interim result display means for displaying events identified using the initial values for the parameters on a display of a portion of the recorded physiological signals;

iii. event categorization means by which the displayed events may be classified into those that have been correctly identified using the initial values for the parameters and those that have been incorrectly identified using those same values; and

iv. parameter modifying means for assigning values to the parameters that are compatible with the event classification made by the event categorization means;

d. scoring means for applying the parameters established by the event identification means in scoring the recorded physiological signals; and

e. result display means for graphically displaying the results of scoring the recorded physiological signals.

2. The apparatus of claim 1 wherein the recorded physiological signals include a perceptible sound signal associated with the generation of audible sound by a subject.

3. The apparatus of claim 2 wherein the waveform associated with the generation of audible sound by a subject is recorded as the perceptible sound signal.

4. The apparatus of claim 2 wherein the envelope of the waveform associated with the generation of audible sound by a subject is recorded as the perceptible sound signal.

5. The apparatus of claim 1 wherein said scoring means cumulates the time for a particular phenomenon throughout the scored physiological signals.

6. The apparatus of claim 1 wherein said scoring means counts the number of occurrences of a particular phenomenon throughout the scored physiological signals.

7. The apparatus of claim 1 further comprising recording means for recording several physiological signals from a subject.

8. The apparatus of claim 7 wherein the recorded physiological signals include a perceptible sound signal associated with the generation of audible sound by a subject.

9. The apparatus of claim 8 wherein the perceptible sound signal is recorded only if its exceeds a pre-established criteria.

10. The apparatus of claim 8 wherein the waveform associated with the generation of audible sound by a subject is recorded as the perceptible sound signal.

11. The apparatus of claim 8 wherein the envelope of the waveform associated with the generation of audible sound by a subject is recorded as the perceptible sound signal.

12. The apparatus of claim 7 wherein said display means replays a sequence of contiguous epochs of previously recorded physiological signals while said recording means continues recording those signals.

13. The apparatus of claim 12 wherein said display means allows selecting a graphic display format in which physiological signals being recorded are displayed while the sequence of contiguous epochs of previously recorded physiological signals are also simultaneously replayed.

14. The apparatus of claim 12 wherein the selected graphic display format overwrites the recorded physiological signals replayed for one epoch with the recorded physiological signals for the successive epoch.

15. The apparatus of claim 12 wherein the selected graphic display format introduces recorded physiological signals that are being replayed along one edge of the display thereof while earlier recorded physiological signals are progressively moved away from that edge.

16. The apparatus of claim 1 wherein the selected display format provides a simultaneous graphic display of several different

physiological signals in which the duration of at least on signal differs from the duration of another signal.

17. The apparatus of claim 1 wherein the selected display format provides a simultaneous graphic display of several different epochs of the same physiological signal in which the duration of each epoch of the signal is the same as that for the other epochs.

18. The apparatus of claim 1 wherein the selected display format provides a graphic display of a single epoch of a physiological signal in which the entire epoch is presented as several successive segments of the physiological signal.

19. The apparatus of claim 18 wherein, in addition to displaying the single epoch of the physiological signal as several successive segments, the selected display format also simultaneously displays a second physiological signal in which the duration of the display for the second signal differs from that of the epoch.

20. The apparatus of claim 1 further comprising manual scoring means whereby an operator of said apparatus may arbitrarily alter the scoring produced by said scoring means.

21. The apparatus of claim 1 wherein the recorded physiological signals include a plurality of EEG signals and the selected display format provides a topographic display of the EEG signals.

22. The apparatus of claim 1 wherein said event identification means includes protocol library means for recording the set of parameters applied by said scoring means for scoring recorded physiological signals, and for subsequently retrieving such recorded set of parameters.

23. The apparatus of claim 22 wherein a set of parameters for scoring recorded physiological signals is automatically retrieved based upon a subject's characteristics.

24. The apparatus of claim 22 wherein:

an initial set of parameters for scoring recorded physiological signals is retrieved based upon a subject's characteristics;

recorded physiological signals are scored by said scoring means using the initial set of parameters; and

a second set of parameters is automatically retrieved, based upon the results of scoring with the initial parameters, for

application by said scoring means in scoring recorded physiological signals.

25. The apparatus of claim 1 wherein said graphic display provided by said result display means includes a hypnogram.

26. The apparatus of claim 1 further comprising means for automatically identifying respiratory disturbances from the recorded physiological signals.

27. An apparatus for analyzing physiological signals recorded from a sleeping subject comprising:

a. signal association means for identifying several physiological signals among those recorded wherein the recorded physiological signals include a perceptible sound signal associated with the generation of audible sound by a subject;

b. display means for selecting among various different graphic display formats a particular display format in which recorded physiological signals are displayed, and for displaying such signals;

c. event identification means for establishing parameters which characterize a specific waveform in the recorded physiological signals that identifies a particular type of event in those signals;

d. scoring means for applying the parameters established by the event identification means in scoring the recorded physiological signals; and

e. result display means for graphically displaying the results of scoring the recorded physiological signals.

28. The apparatus of claim 27 wherein the waveform associated with the generation of audible sound by a subject is recorded as the perceptible sound signal.

29. The apparatus of claim 27 wherein the envelope of the waveform associated with the generation of audible sound by a subject is recorded as the perceptible sound signal.

30. The apparatus of claim 27 wherein said scoring means cumulates the time for a particular phenomenon throughout the scored physiological signals.

31. The apparatus of claim 27 wherein said scoring means counts the number of occurrences of a particular phenomenon throughout the scored physiological signals.

32. The apparatus of claim 27 further comprising recording means for recording several physiological signals from a subject.

33. The apparatus of claim 32 wherein the perceptible sound signal is recorded only if its exceeds a pre-established criteria.

34. The apparatus of claim 32 wherein the waveform associated with the generation of audible sound by a subject is recorded as the perceptible sound signal.

35. The apparatus of claim 32 wherein the envelope of the waveform associated with the generation of audible sound by a subject is recorded as the perceptible sound signal.

36. The apparatus of claim 32 wherein said display means replays a sequence of contiguous epochs of previously recorded physiological signals while said recording means continues recording those signals.

37. The apparatus of claim 36 wherein said display means allows selecting a graphic display format in which physiological signals being recorded are displayed while the sequence of contiguous epochs of previously recorded physiological signals are also simultaneously replayed.

38. The apparatus of claim 36 wherein the selected graphic display format overwrites the recorded physiological signals replayed for one epoch with the recorded physiological signals for the successive epoch.

39. The apparatus of claim 36 wherein the selected graphic display format introduces recorded physiological signals that are being replayed along one edge of the display thereof while earlier recorded physiological signals are progressively moved away from that edge.

40. The apparatus of claim 27 wherein the selected display format provides a simultaneous graphic display of several different physiological signals in which the duration of at least one signal differs from the duration of another signal.

41. The apparatus of claim 27 wherein the selected display format provides a simultaneous graphic display of several different epochs of the same physiological signal in which the duration of each epoch of the signal is the same as that for the other epochs.

42. The apparatus of claim 27 wherein the selected display format provides a graphic display of a single epoch of a

physiological signal in which the entire epoch is presented as several successive segments of the physiological signal.

43. The apparatus of claim 42 wherein, in addition to displaying the single epoch of the physiological signal as several successive segments, the selected display format also simultaneously displays a second physiological signal in which the duration of the display for the second signal differs from that of the epoch.

44. The apparatus of claim 27 wherein the selected display format presents a display that graphically correlates the perceptible sound signal with another physiological signal for intervals during which the subject generates audible sound.

45. The apparatus of claim 27 wherein the selected display format presents a display that graphically correlates the perceptible sound signal with other events identified in another physiological signal by said scoring means for intervals during which the subject generates audible sound.

46. The apparatus of claim 27 further comprising manual scoring means whereby an operator of said apparatus may arbitrarily alter the scoring produced by said scoring means.

47. The apparatus of claim 27 wherein the recorded physiological signals include a plurality of EEG signals and the selected display format provides a topographic display of the EEG signals.

48. The apparatus of claim 27 wherein said event identification means includes:

i. initialization means for establishing initial values for the parameters;

ii. interim result display means for displaying events identified using the initial values for the parameters on a display of a portion of the recorded physiological signals;

iii. event categorization means by which the displayed events may be classified into those that have been correctly identified using the initial values for the parameters and those that have been incorrectly identified using those same values; and

iv. parameter modifying means for assigning values to the parameters that are compatible with the event classification made by the event categorization means.

49. The apparatus of claim 27 wherein said event identification means includes protocol library means for recording the set of parameters applied by said scoring means for scoring

recorded physiological signals, and for subsequently retrieving such recorded set of parameters.

50. The apparatus of claim 49 wherein a set of parameters for scoring recorded physiological signals is automatically retrieved based upon a subject's characteristics.

51. The apparatus of claim 47 wherein:

an initial set of parameters for scoring recorded physiological signals is retrieved based upon a subject's characteristics;

recorded physiological signals are scored by said scoring means using the initial set of parameters; and

a second set of parameters is automatically retrieved, based upon the results of scoring with the initial parameters, for application by said scoring means in scoring recorded physiological signals.

52. The apparatus of claim 27 further comprising means for automatically identifying respiratory disturbances from the recorded physiological signals.

53. An apparatus for analyzing physiological signals recorded from a sleeping subject comprising:

a. signal association means for identifying several physiological signals among those recorded wherein the recorded physiological signals include a plurality of EEG signals;

b. display means for selecting among various different graphic display formats a particular display format in which recorded physiological signals are displayed, and for displaying such signals, said display formats including a topographic display of the EEG signals.

54. The apparatus of claim 53 further comprising:

c. event identification means for establishing parameters which characterize a specific waveform in the recorded physiological signals that identifies a particular type of event in those signals;

d. scoring means for applying the parameters established by the event identification means in scoring the recorded physiological signals; and

e. result display means for graphically displaying the results of scoring the recorded physiological signals.

55. An apparatus for recording physiological signals comprising:

a. recording means for continuously recording at least 10 different physiological signals; and

b. display means for selecting among various differ nt graphic display formats a particular display format in which recorded physiological signals are displayed, and for displaying such signals, said display means displaying either physiological signals being recorded or replaying a sequence of contiguous epochs of previously recorded physiological signals while said recording means continues recording those signals.

56. The apparatus of claim 55 wherein said display means allows selecting a graphic display format in which physiological signals being recorded are displayed while the sequence of contiguous epochs of previously recorded physiological signals are also simultaneously replayed.

57. The apparatus of claim 55 wherein the selected graphic display format overwrites the recorded physiological signals replayed for one epoch with the recorded physiological signals for the successive epoch.

58. The apparatus of claim 55 wherein the selected graphic display format introduces recorded physiological signals that are being replayed along one edge of the display thereof while earlier recorded physiological signals are progressively moved away from that edge.

59. The apparatus of claim 55 wherein the recorded physiological signals include a plurality of EEG signals and the selected display format provides a topographic display of the EEG signals.

60. The apparatus of claim 55 further comprising:

c. event identification means for establishing parameters which characterize a specific waveform in the recorded physiological signals that identifies a particular type of event in those signals;

d. scoring means for applying the parameters established by the event identification means in scoring the recorded physiological signals; and

e. result display means for graphically displaying the results of scoring the recorded physiological signals.

61. The apparatus of claim 60 wherein said event identification means includes:

i. initialization means for establishing initial values for the parameters;

ii. interim result display means for displaying events identified using the initial values for the parameters on a display of a portion of the recorded physiological signals;

iii. event categorization means by which the displayed events may be classified into those that have been correctly identified using the initial values for the parameters and those that have been incorrectly identified using those same values; and

iv. parameter modifying means for assigning values to the parameters that are compatible with the event classification made by the event categorization means.

62. An apparatus for analyzing physiological signals recorded from a subject comprising:

a. signal association means for ~~identifying~~ recording several physiological signals among those recorded;

b. display means for selecting among various different graphic display formats a particular display format in which recorded physiological signals are displayed, and for displaying such signals; and

c. commenting means for entering a textual comment associated with a particular time interval in the recorded physiological signals, said display means being adapted for presenting a display of the recorded physiological signals at the time interval associated with the comment upon identification of the comment.

63. The apparatus of claim 62 further comprising:

d. event identification means for establishing parameters which characterize a specific waveform in the recorded physiological signals that identifies a particular type of event in those signals;

e. scoring means for applying the parameters established by the event identification means in scoring the recorded physiological signals; and

f. result display means for graphically displaying the results of scoring the recorded physiological signals.

64. The apparatus of claim 63 wherein said event identification means includes:

i. initialization means for establishing initial values for the parameters;

ii. interim result display means for displaying events identified using the initial values for the parameters on a display of a portion of the recorded physiological signals;

iii. event categorization means by which the displayed events may be classified into those that have been correctly identified using the initial values for the parameters and those that have been incorrectly identified using those same values; and

iv. parameter modifying means for assigning values to the parameters that are compatible with the event classification made

by the event categorization means.

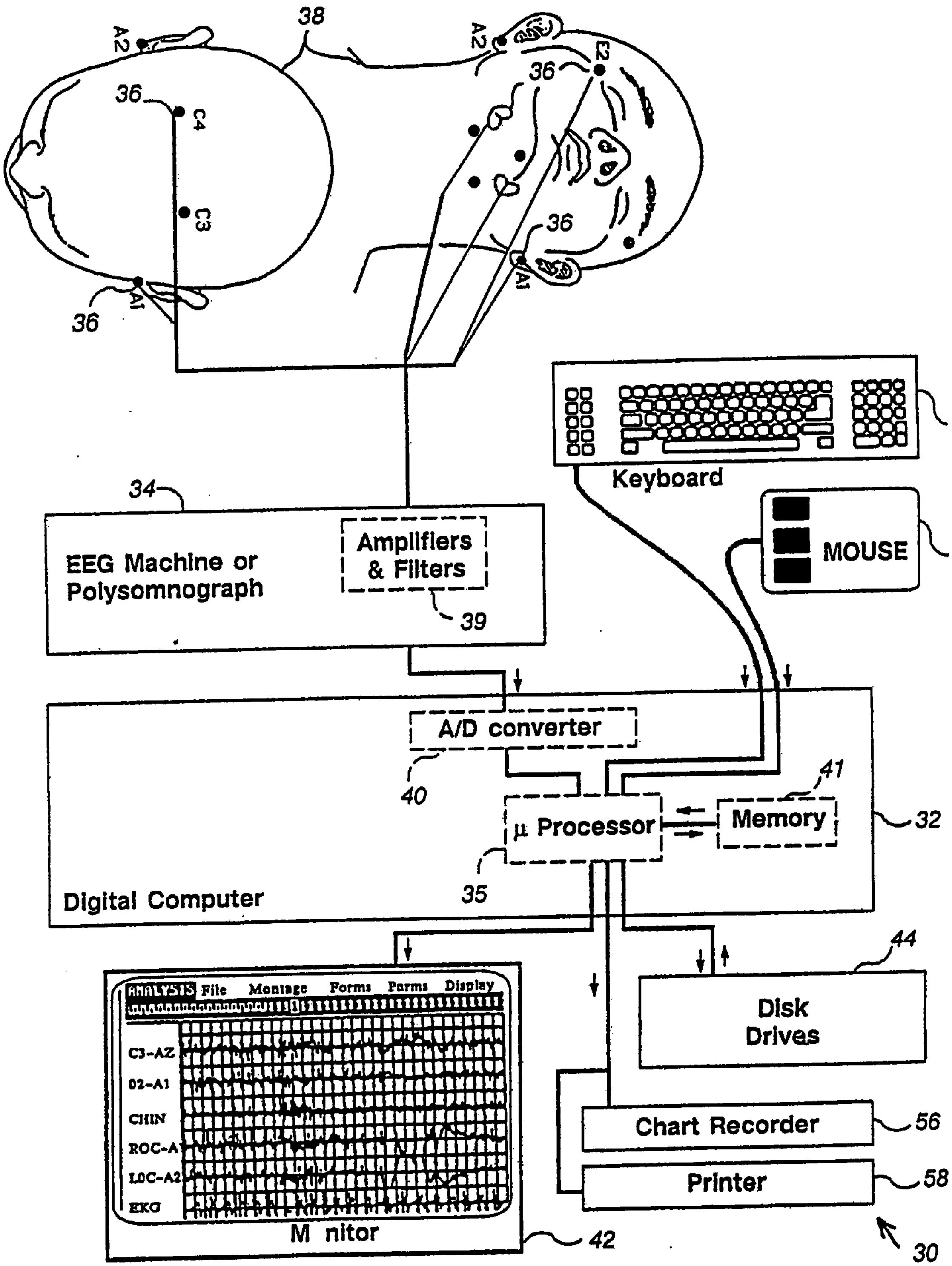
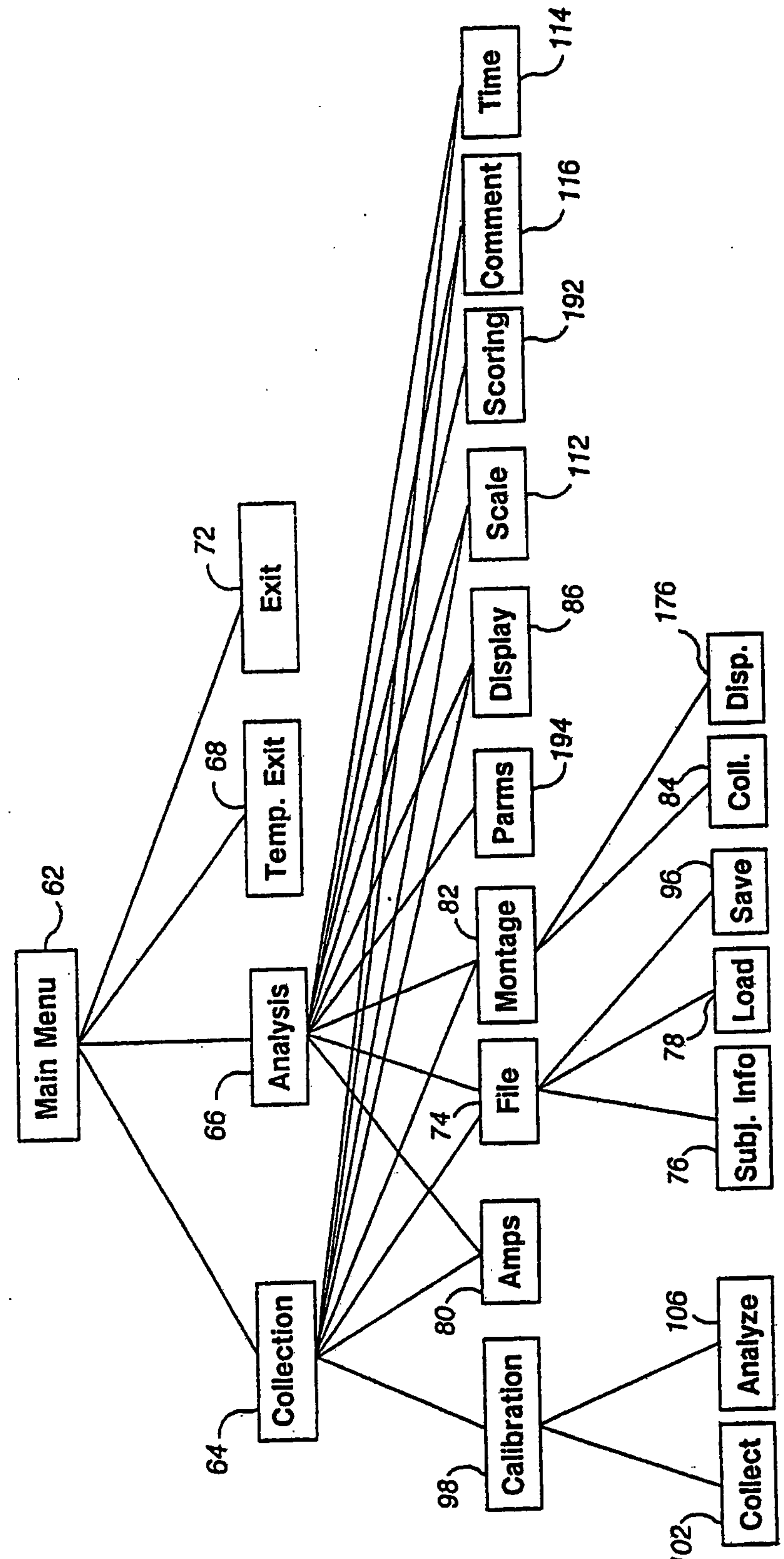

38
A2
A2
E2
36
36
C4
C3
36
A1
A1
36
52
Keyboard
MOUSE
54
34
EEG Machine or
Polysomnograph
Amplifiers
& Filters
39
A/D converter
40
41
µ Processor
Memory
32
35
Digital Computer
44
Disk
Drives
File
Montage
Forms
Parms
Display
C3-AZ
02-A1
CHIN
ROC-A1
LOC-A2
EKG
M nitor
42
Chart Recorder
56
Printer
58
30

FIG.1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Analysis
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Temp. Exit
68
Exit
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File
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Subj. Info
76
Load
78
Amps
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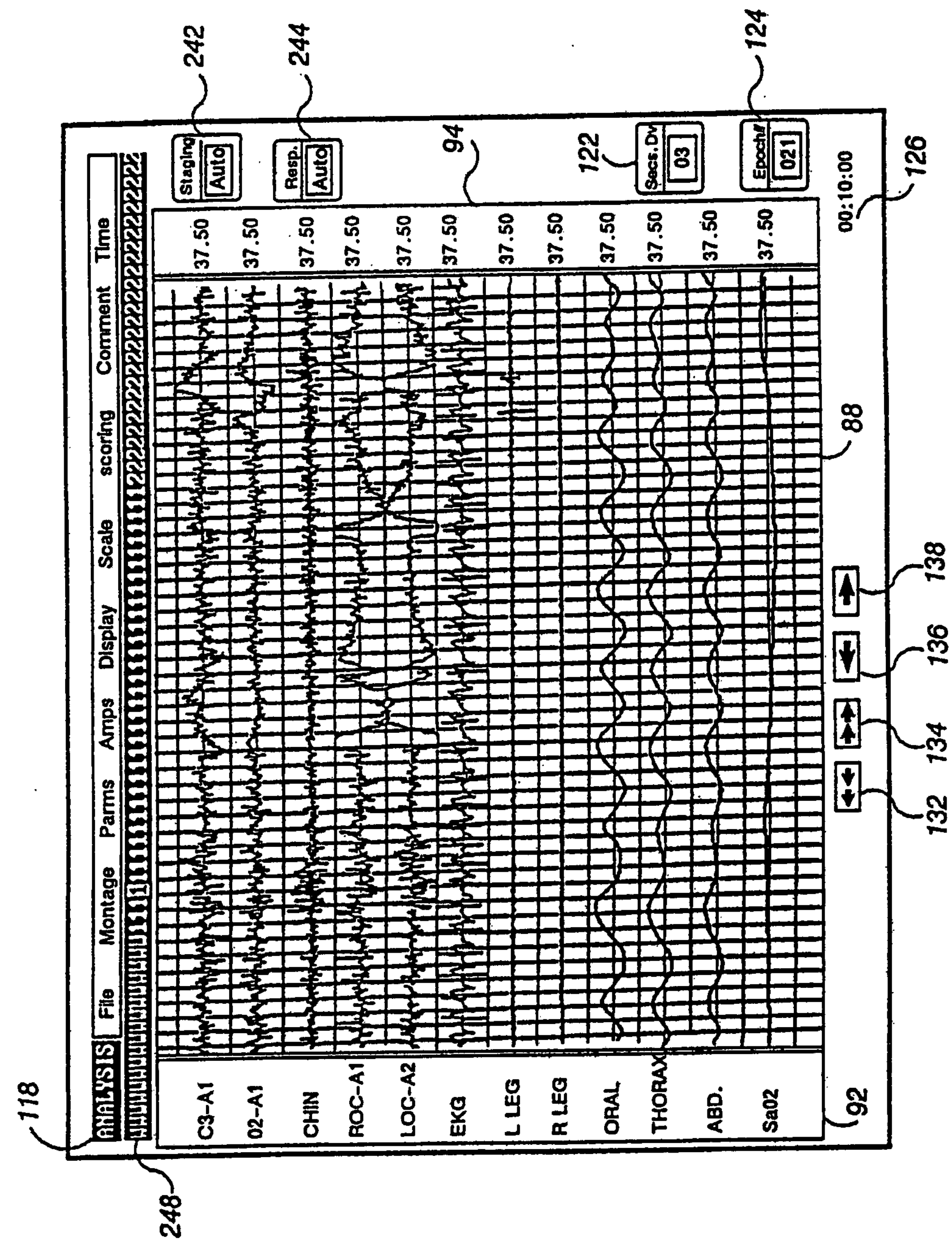
Montage
82
Coll.
84
Display
86
Save
96
Calibration
98
Collect
102
Analyze
106
Scale
112
Time
114
Comment
116
Disp.
176
Scoring
192
Parms
194

FIG. 2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Amps
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Scale
scoring
Comment
Time
Staging
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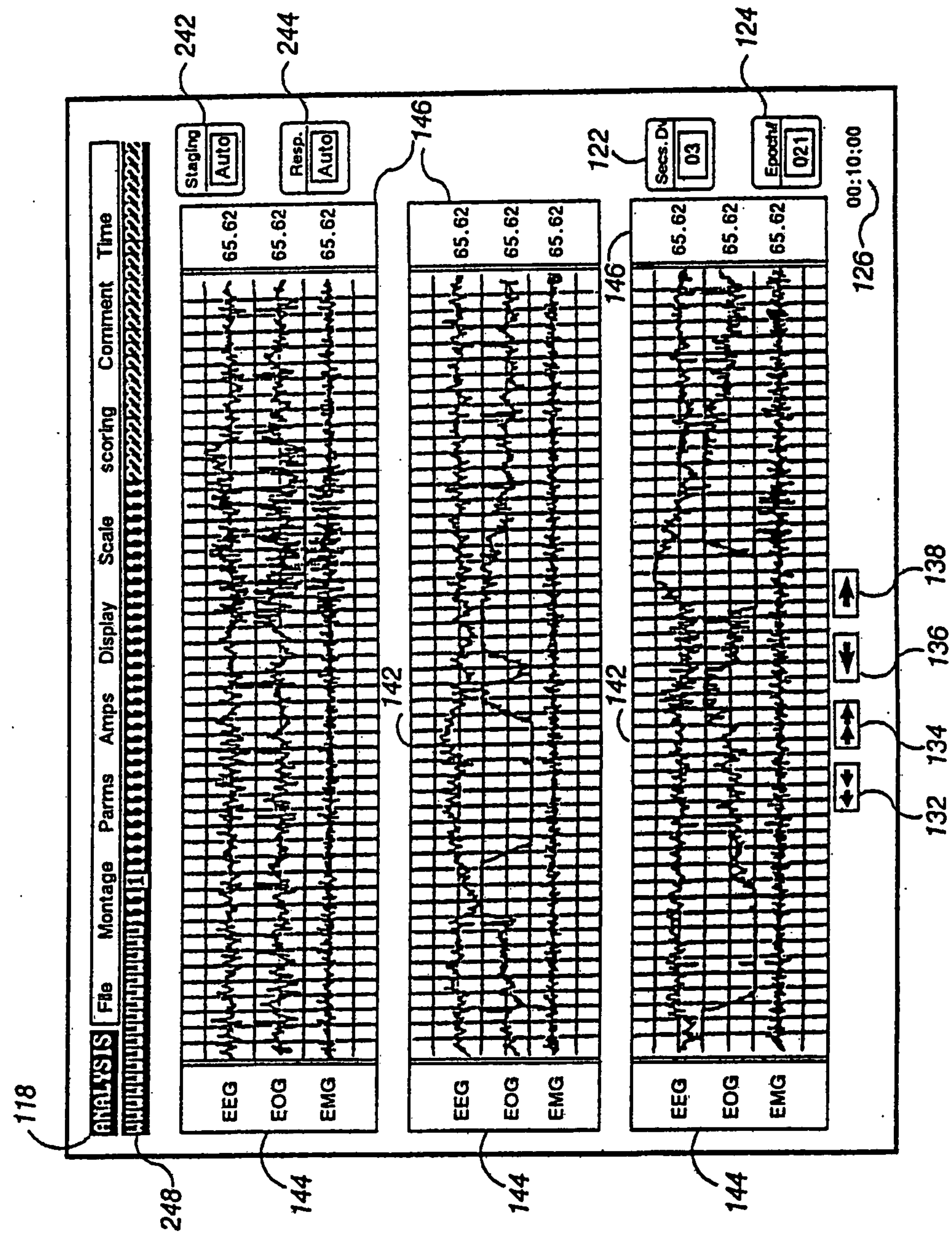
Resp.
Auto
Secs.Dv
03
Epoch#
021
00:10:00
C3-A1
02-A1
CHIN
ROC-A1
LOC-A2
EKG
L LEG
R LEG
ORAL
THORAX
ABD.
Sa02
37.50
118
248
242
244
94
122
124
126
88
92
132
134
136
138

FIG. 3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Amps
Display
Scale
scoring
Comment
Time
Staging
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Resp.
Auto
Secs.Di
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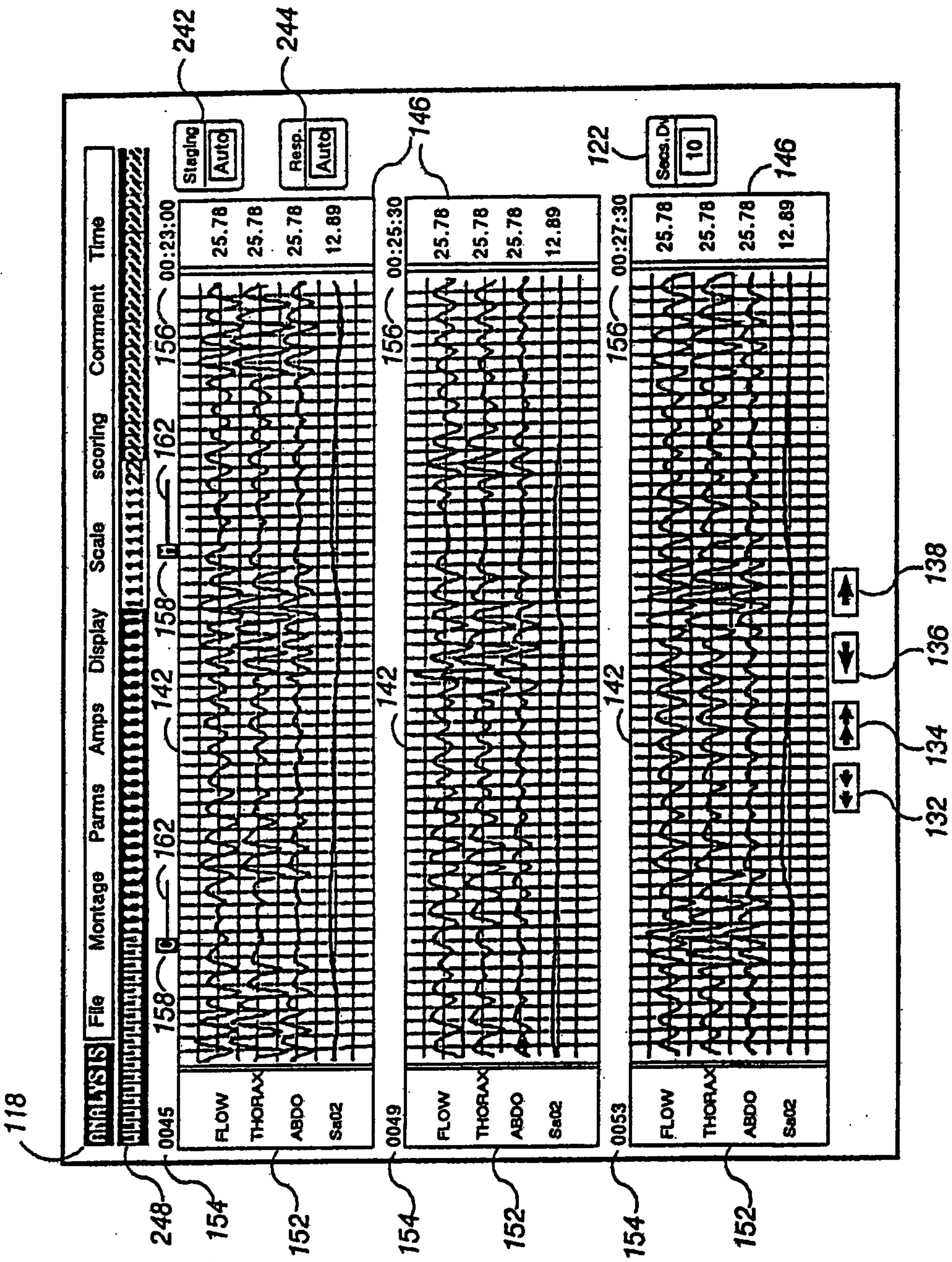
Epoch/
021
00:10:00
EEG
EOG
EMG
65.62
118
248
144
142
146
242
244
122
124
126
132
134
136
138

FIG. 4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Parms
Amps
Display
Scale
scoring
Comment
Time
Staging
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Resp.
Auto
Secs.Di
10
0045
00:23:00
0049
00:25:30
0053
00:27:30
FLOW
THORAX
ABDO
Sa02
25.78
25.78
25.78
12.89
118
122
132
134
136
138
142
146
152
154
156
158
162
242
244
248

FIG. 5

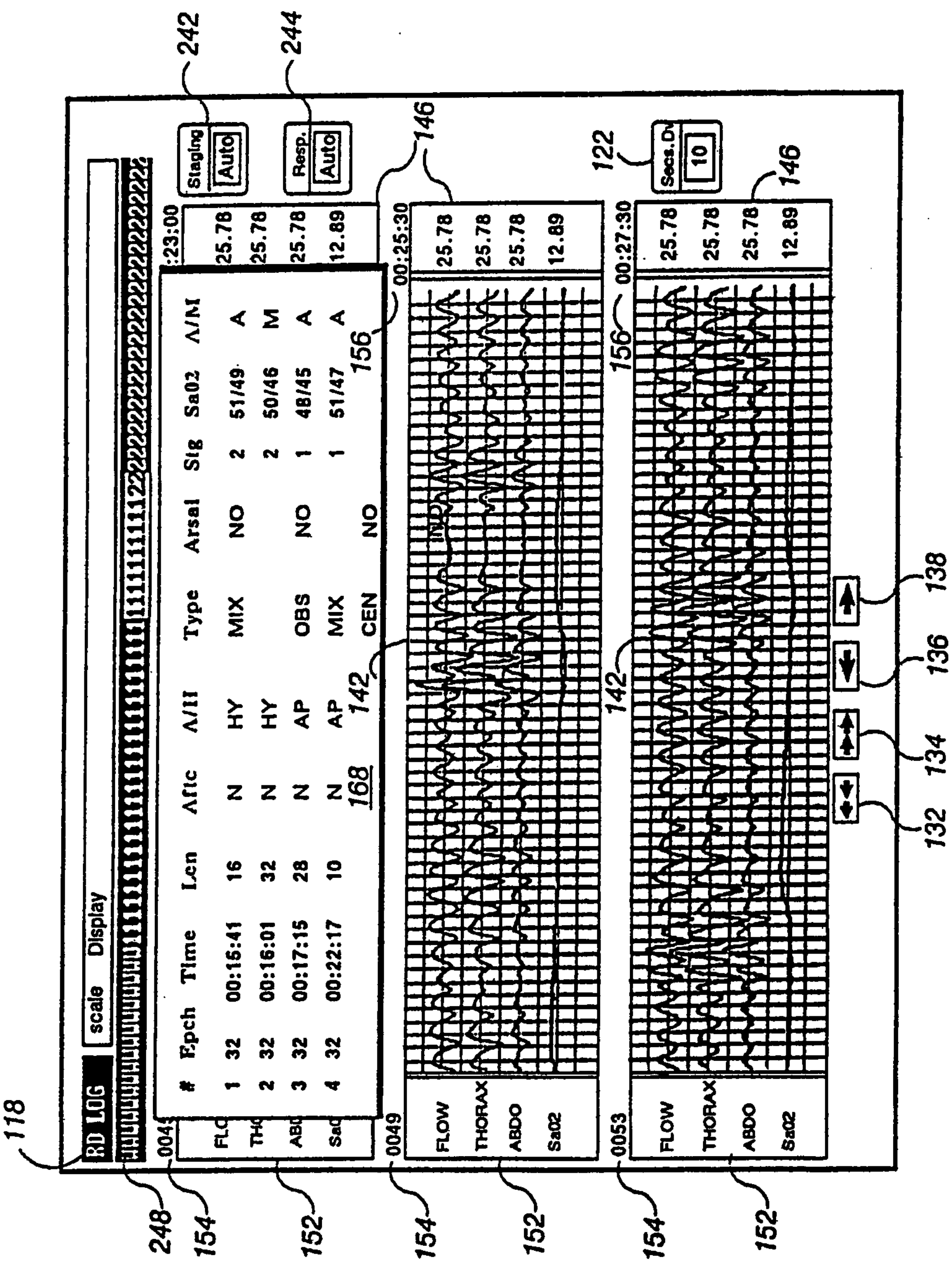
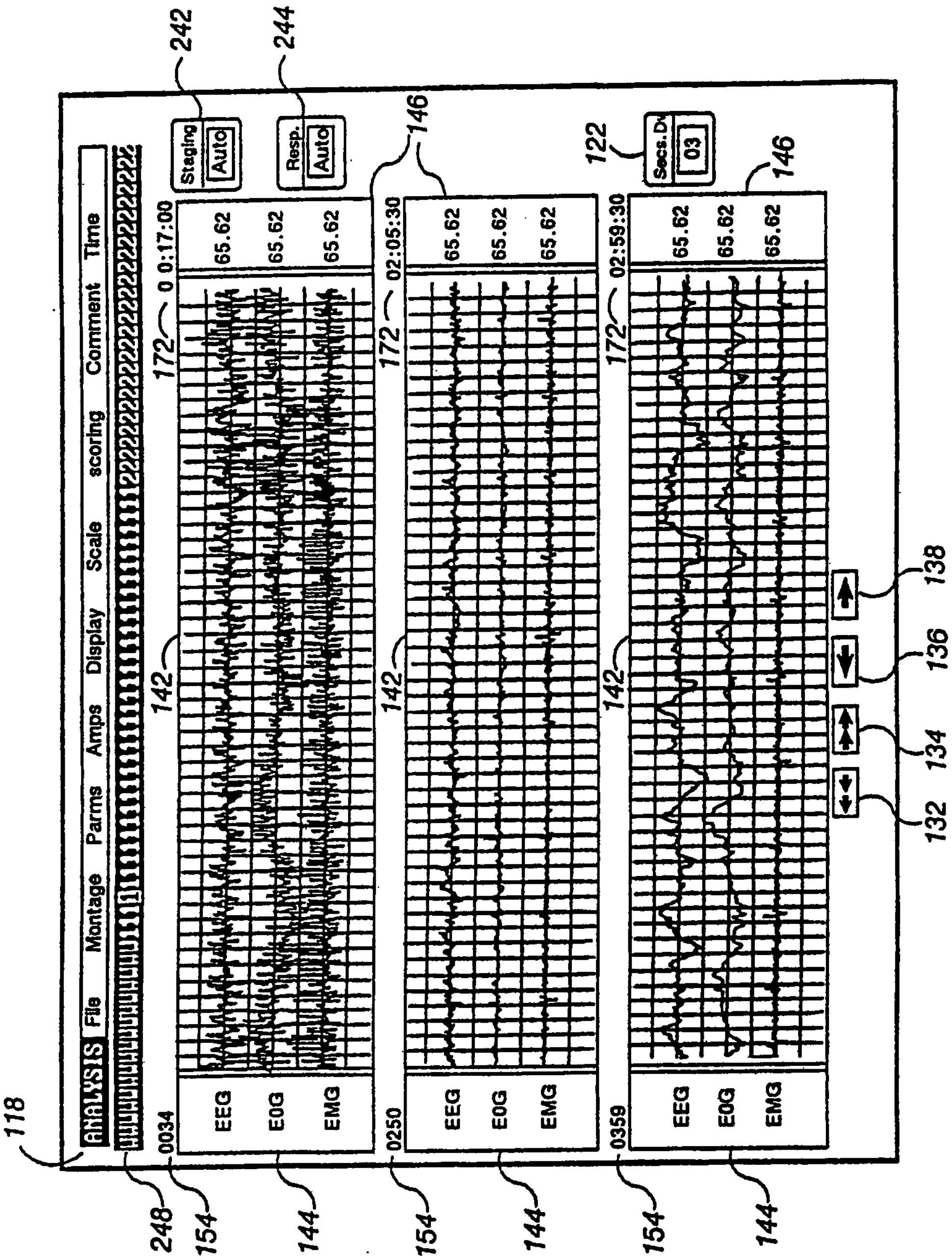

RD LOG
scale
Display
Staging
Auto
Resp.
Auto
Secs.Div
10
Epch Time Len Afic A/H Type Arsal Sig Sa02 A/M
1 32 00:16:41 16 N HY MIX NO 2 51/49 A
2 32 00:16:01 32 N HY 2 50/46 M
3 32 00:17:15 28 N AP OBS NO 1 48/45 A
4 32 00:22:17 10 N AP MIX 1 51/47 A
CEN NO
00:25:30
00:27:30
0049
0053
FLOW
THORAX
ABDO
Sa02
25.78
12.89
118
122
132
134
136
138
142
146
152
154
156
168
242
244
248

FIG. 6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Staging
Auto
Resp.
Auto
Secs.Di
03
0034
0250
0359
EEG
E0G
EMG
0 0:17:00
02:05:30
02:59:30
65.62
118
242
244
146
122
172
142
248
154
144
132
134
136
138

FIG. 7

PARAMETER MENU **File** Edit Transfer Hypnogram

Current values

222 amplitude — frequency — regularity

			pp	224	(Hz)	226	228		232		
202	1.	Alpha	30 uV	8.00	to	12.00	1	30	8.00	12.00	1
204	2.	Spindle	30 uV	13.00	to	15.00	2	30	13.00	15.00	2
			single pk								
206	3.	Slow wave	35 uV	.50	to	2.50		35	0.50	2.50	
208	4.	K complex	35 uV	3.00	to	6.00		35	3.00	2.50	
212	5.	REM	75 uV	2.00	to	10.00		75	2.00	6.00	
214	6.	high Emg	40 uV					75	2.00	10.00	
								40			

FIG. 8

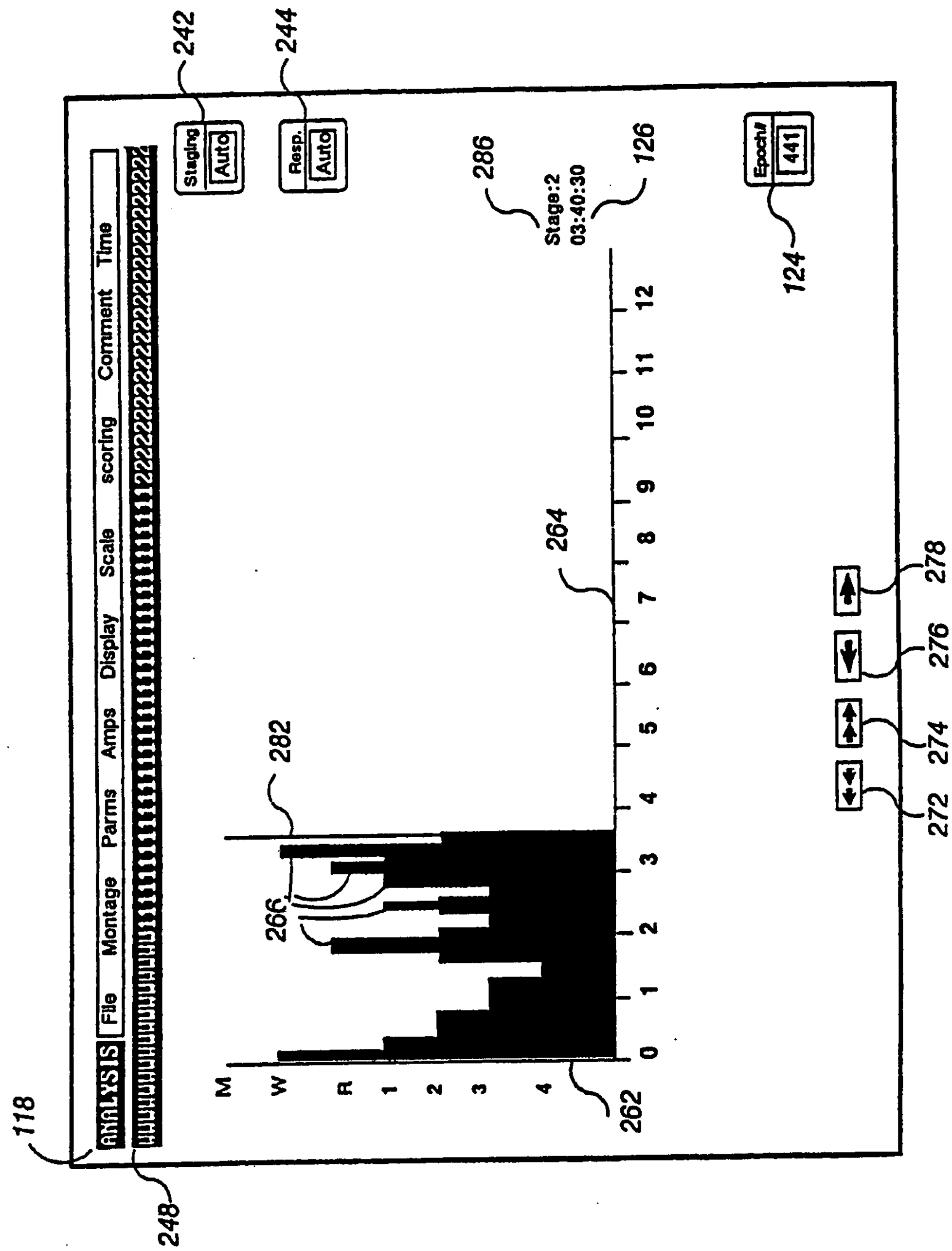
ANALYSIS
File
Montage
Parms
Amps
Display
Scale
scoring
Comment
Time
Staging
Auto
Resp.
Auto
Epoch#
441
Stage:2
03:40:30
M
W
R
1
2
3
4
0 1 2 3 4 5 6 7 8 9 10 11 12
118
242
244
248
262
264
266
272
274
276
278
282
286
126
124

FIG. 9

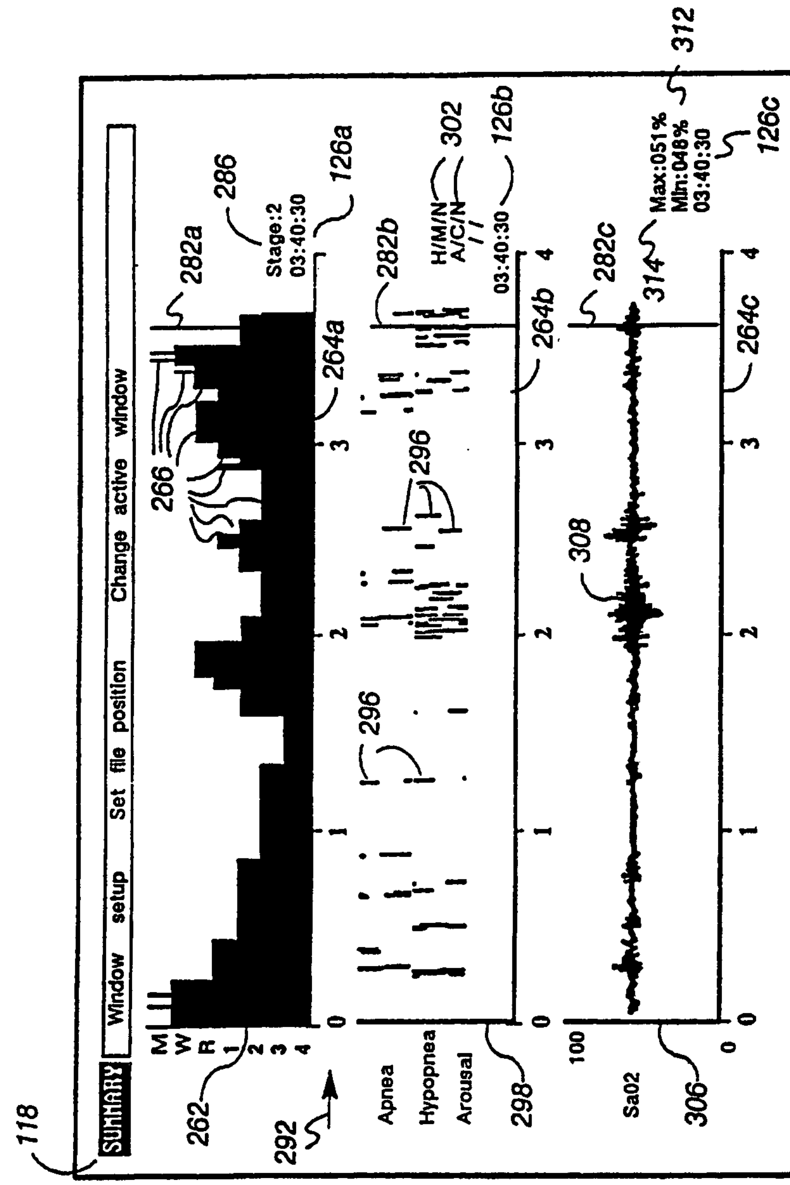
SUMMARY
Window setup Set file position Change active window
M
W
R
1
2
3
4
Stage:2
03:40:30
Apnea
Hypopnea
Arousal
H/M/N
A/C/N
/ /
03:40:30
Sa02
100
0
Max:051%
Min:048%
03:40:30
0
1
2
3
4
118
262
292
298
306
266
282a
286
126a
264a
282b
302
126b
264b
296
282c
314
312
126c
264c
308
242
274
276
278

FIG. 10

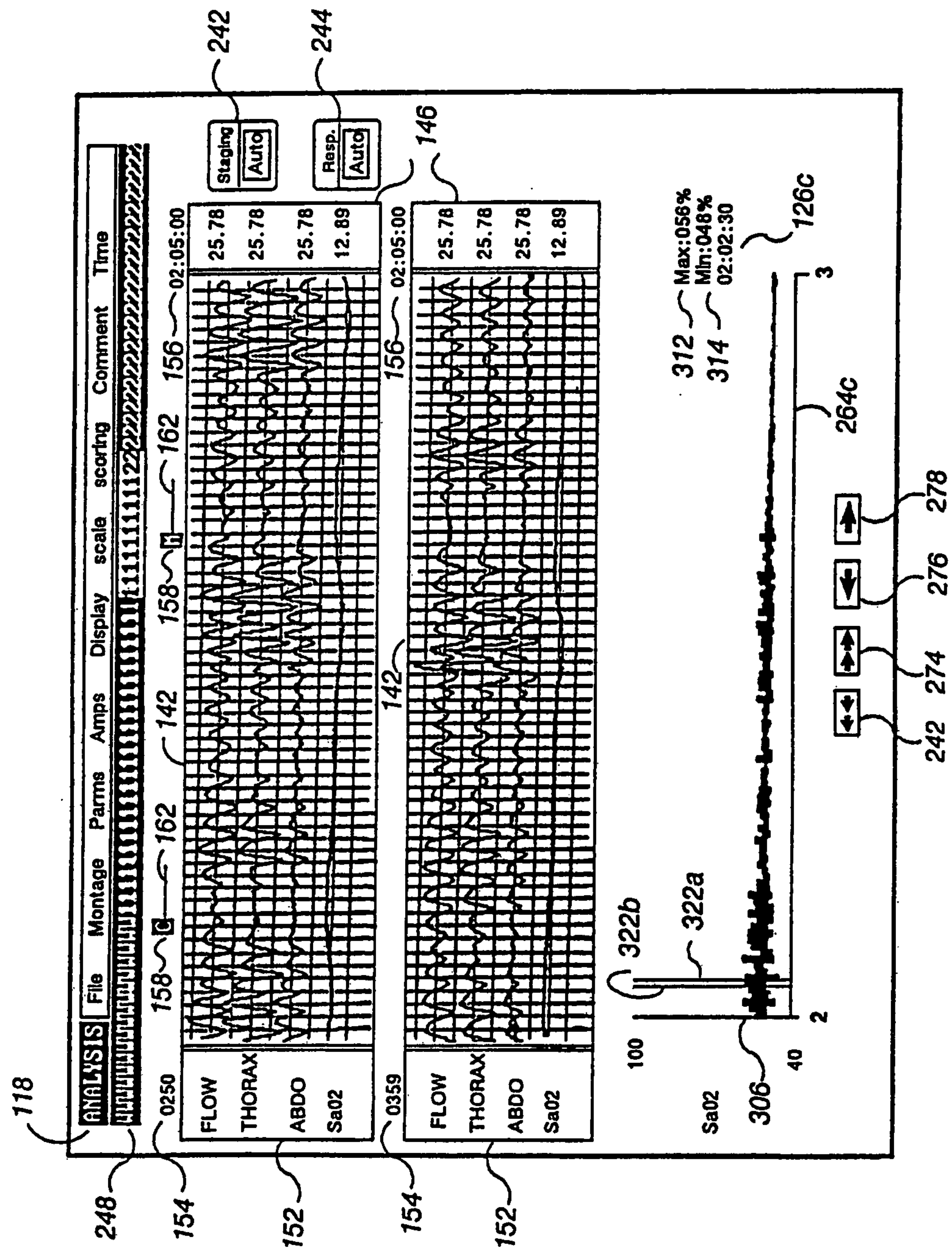
ANALYSIS
File
Montage
Parms
Amps
Display
scale
scoring
Comment
Time
Staging
Auto
Resp.
Auto
0250
FLOW
THORAX
ABDO
Sa02
02:05:00
25.78
25.78
25.78
12.89
0359
FLOW
THORAX
ABDO
Sa02
02:05:00
25.78
25.78
25.78
12.89
Max:056%
Min:046%
02:02:30
Sa02
100
40
2
3
118
248
154
152
154
152
158
162
142
158
162
156
156
142
146
242
244
322b
322a
306
312
314
126c
264c
242
274
276
278

FIG. 11

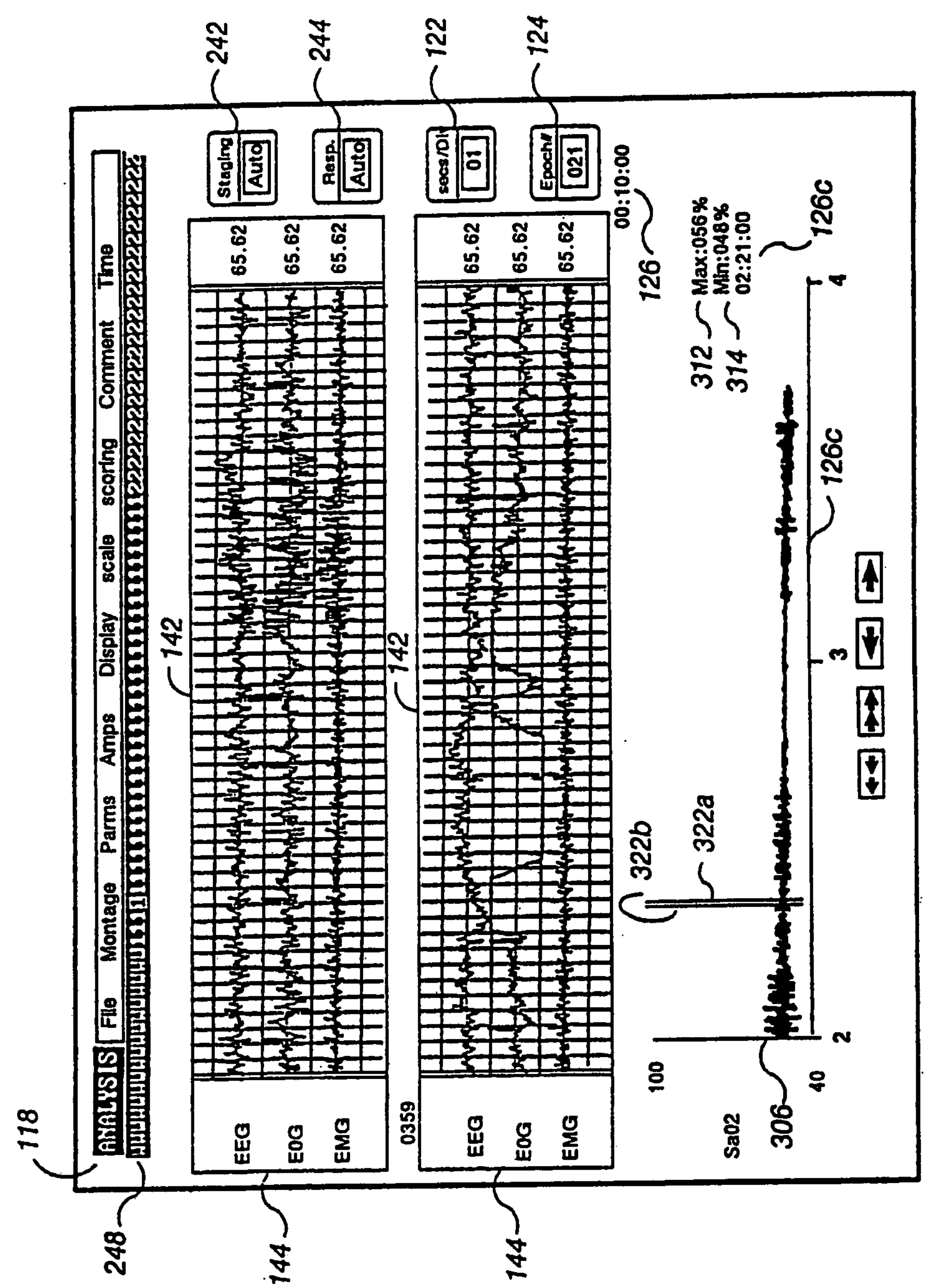
ANALYSIS
File
Montage
Parms
Amps
Display
scale
scoring
Comment
Time
Staging
Auto
Resp.
Auto
secs/Di
01
Epoch#
021
00:10:00
EEG
E0G
EMG
65.62
65.62
65.62
0359
EEG
E0G
EMG
65.62
65.62
65.62
Max:056%
Min:048%
02:21:00
Sa02
100
40
2
3
4
118
248
144
144
142
142
242
244
122
124
126
126c
126c
312
314
322a
322b
306

FIG. 12

INTERNATIONAL SEARCH REPORT

International Application No PCT/US90/07189

I. CLASSIFICATI N OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5): G06F 15/42, A61B 5/04

U.S. CL.: 364/413.05, 128/731

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S. CL.	364/413.02, 413.05, 413.06; 128/709, 710, 712,731

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
Y	WO,A WO 88/10093 (MARTENS ET AL.), 29 December 1988 (29.12.88), note entire document, especially pages 12-16 and 64.	1,24,48, 61,62,64
Y	US,A 4,739,772 (HOKANSON ET AL.), 26 April 1988 (26.04.88), note column 8, lines 16-30 and figures 6 and 7.	12,55,56
Y	US,A 4,649,482 (RAVIV ET AL.) 10 March 1987 (10.03.87), note line 40 of column 8 to line 68 of column 10 and figures 5 and 7.	21,47,53, 59
A	International Journal of Bio-Medical Computing, vol. 19, no. 1, July 1986, Ray et al., "Computer sleep stage scoring -- an expert system approach", pages 43-61 (abstract only provided).	1,27
A	US,A 4,336,810 (ANDERSON ET AL.) 29 June 1982 (29.06.82), note column 4, lines 10-36 and figure 1.	1,24,48, 61,69

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
27 MARCH 1991	16 APR 1991
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/US	For Andre Robinson / DAVID HUNTLEY

III. DOCUMENTS C NSIDERED TO BE RELEVANT (CONTINUED FR M THE SECOND SHEET)		
Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No [18]
A	US,A 4,776,345 (COHEN ET AL.) 11 October 1988 (11.10.88), note entire document.	1-64